guide to mars

Patrick Moore
F.R.A.S.

guide to mars Patrick Moore MULLER

GUIDE TO MARS

Mars has always been regarded as the most Earth-like of the planets, and the one other world where life might well exist. Now that Venus, the second of our planetary neighbours, has been shown to be so obviously unfriendly, it seems that Mars must be our first target in space following successful journeys to the Moon.

Patrick Moore has been an observer of Mars for many years. His book first appeared in 1954, and succeeding editions were brought up to date, but when another edition was called for in 1963 it seemed best to re-cast the entire work in the light of recent researches. This has been done, and the length and scope extended, though the original pattern has been retained.

The book gives a general description of Mars and its various problems, ranging from the nature of the dark areas to the dwarf satellites and the controversial canals. The author has included the results of his own work and has also given an extensive reference-list which will enhance the value of the book for serious students.

This is, in fact, an introduction to Mars – the Red Planet, one of the most fascinating heavenly bodies known to mankind.

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GUIDE TO MARS

by

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FOREWORD TO THE SECOND EDITION

THE original edition of this book appeared some years ago, and much has happened since. Our basic ideas about Mars remain unchanged, but at least we know more about the atmosphere, and, of course, there have been spectacular developments in the field of space research. The first rocket to Mars was launched in 1962; what will happen in the near future remains to be seen.

Much of the book has been revised, and I have done my best to include the new information. Meanwhile, I must repeat my thanks to the Mount Wilson and Palomar Observatories for allowing me to use their photographs of Mars, and also to the Houghton Mifflin Press, who have given me permission to reproduce the drawing by Percival Lowell, originally published in his famous book *Mars* more than half a century ago.

PATRICK MOORE

East Grinstead,
January 1965.

CHAPTER ONE

THE RED WORLD

All through the winter of 1964–5, the planet Mars was a striking feature of the evening sky. It far outshone even the brightest stars, and its strong red colour made it quite unmistakable. What made it even more interesting, perhaps, was the fact that two Earth-made rockets, one American and one Russian, were travelling toward it.

The idea of sending a rocket from one world to another seemed very far-fetched only a few years ago. In the 1930s, for instance, members of Interplanetary Societies were generally classed together with what may be termed the "fringe" of flat-earth enthusiasts, astrologers and the like. Under the circumstances, it is amazing how quickly our ideas have changed since the ascent of Sputnik I, the first artificial satellite, in 1957.

Sputnik I was a Russian triumph, and it was the Russians, too, who sent up the pioneer probe to the Red Planet—*Mars I*, a complex unmanned vehicle carrying instruments of all sorts, together with a television camera. They were not, of course, alone in the field of space research, and the United States workers have made contributions which are just as outstanding; but for the moment, let us defer considerations of rockets and concentrate upon Mars itself.

When I wrote the first edition of this book, nearly ten years ago, I spent several pages in giving what was, I hoped, a brief and concise picture of the Universe. At that

time space research was still in its infancy, and few people outside scientific circles were familiar with terms such as "escape velocity", "sidereal period" and "transfer orbit". The situation now is very different, and space-research expressions are in everyday use. So it is, I feel, safe for me to give the briefest of introductions.

The Solar System, in which we live, consists of one star (the Sun); nine planets, of which the Earth comes third in order of distance; and various lesser bodies, such as the comets, meteors, asteroids or minor planets, and the satellites or moons. There is nothing at all remarkable about the Sun, and the only reason why it appears so brilliant is that it is very close to us on the astronomical scale. Its distance from us is a mere 93,000,000 miles, whereas the other stars, which are suns in their own right, are much more remote; even the nearest of them lies 25 million million miles away, so that a ray of light, moving at 186,000 miles per second, takes over 4 years to do the journey. Many of the stars, too, are much more luminous than our Sun; Rigel, in the glorious winter constellation of Orion, seems to be the equal of 50,000 Suns put together, and we know of stars which shine with at least a million times the candlepower of the Sun.

The planets move round our Sun at various distances and in various periods. They are divided into two obvious groups, separated by a wide gap. The inner group is made up of four relatively small worlds, Mercury, Venus, the Earth and Mars, while the outer groups consists of four giants—Jupiter, Saturn, Uranus and Neptune—together with the peculiar little planet Pluto, which has given astronomers a series of theoretical headaches ever since it was discovered in 1930, and which may prove to be in a class of its own, as there have been suggestions that it is nothing more than a former moon of Neptune which

somehow broke free and moved off in its own orbit (1). The thousands of dwarf planets or asteroids move, in general, between the paths of Mars and Jupiter, though some of them may wander away from the main swarm.

Most of the planets are quite unlike the Earth. The giants, for instance, are not "solid" in the conventional sense; their surfaces, at least, are made up of gas, and they are intensely cold, so that they are quite unable to support life of the sort familiar to us. Of the members of the inner group, Mercury, at a distance of 36,000,000 miles from the Sun, is a most unfriendly world, much smaller than the Earth and with practically no atmosphere, so that it too must presumably be lifeless. This leaves us with our nearest planetary neighbours, Venus and Mars.

Venus is about the same size as our world, and is closer to the Sun than we are. It must therefore receive more heat, and is likely to be a tropical planet. Unfortunately we know very little about it, since its surface is permanently hidden by its opaque atmosphere. In late 1962 the Americans dispatched their rocket *Mariner II* toward Venus (an earlier Russian attempt had been unsuccessful). The results were most significant. *Mariner* passed about 21,000 miles from the planet, and sent back information showing that the surface temperature of Venus was very high—around +800 degrees Fahrenheit. If this is even approximately correct, no life built upon the terrestrial pattern can exist there, though it is too early to judge, and doubts have recently been cast upon the idea of an intensely hot Venus. The rotation period has never been known; many estimates have been made, and I have summarized them elsewhere (2); measures made in 1963–4 suggest that it may be remarkably slow, but this too has been questioned.

Many people are surprised to find that Venus is considerably closer than Mars. At its nearest it may approach us to within 24,000,000 miles, so that it then is only about one hundred times as remote as the Moon—which is not, of course, an independent planet, but a satellite of the Earth. Mars, however, has a minimum distance of about 34,000,000 miles. Moreover it is comparatively small; its diameter is 4,219 miles, not much more than half that of the Earth or Venus, and so it is not so easy to study as might be thought. The saving grace is that its atmosphere is thin and more or less transparent, so that we have no difficulty in seeing the actual surface.

During the last decade the astronomical situation has changed also in another way. Up to the time when rockets became recognized scientific instruments instead of unreliable toys, professional astronomers were interested mainly in the remote stars and star-systems. This was reasonable enough; our Sun and its family of planets count for little in the Universe as a whole, and are no more important than a single grain of sand in the Sahara. For this reason, the world's great telescopes, such as the giant 200-inch reflector at Palomar in California, were used almost exclusively for stellar studies, and virtually no time was spent in studying the surfaces of the Moon and planets. Amateur observers were entrusted with this kind of work, and they carried it out excellently. Now, however, it has become clear that the Moon and the nearer planets are within range, so that it is essential to find out as much about them as we can, so that professionals as well as amateurs are taking an active interest in them.

Various technical works have been published, and, predictably, some of them have dealt with Mars; at this point it is worth noting the book *Physics of the Planet Mars*,

by the French astronomer Gérard de Vaucouleurs, which is a positive mine of information. My present aim is simply to give a general introduction to the study of Mars which will, I hope, enable relative beginners in astronomy to study more technical papers without feeling "out of their depth". Besides, the day of the amateur astronomer is far from over, and I doubt whether it will ever be over; there is still much that he can do.

For most of this book I propose to concentrate upon Mars as a world. The first essential is to give an account of the way in which it moves, but to go into detail would involve mathematics—and those who are mathematically inclined will, in any case, need a book written at a more advanced technical level than this one; so let us be brief.

Mars must have been known from very ancient times, and the philosophers of Ancient Greece were well aware that it was not a star. The stars seem to stay in the same relative positions for year after year, century after century; they are moving about in space at great velocities and in all sorts of directions, but they are so remote that their individual or "proper" motions are very slight, and the star-groups which we see today are almost the same as those which must have been seen by Julius Cæsar or the builders of the Pyramids. The planets, however, seem to move about against the starry background. They were named after mythological deities, and we have to admit that the names are appropriate enough. The largest of the planets is known as Jupiter, the King of Olympus; Venus, the beautiful "Evening Star", was named in honour of the Goddess of Love; Mercury, quick-moving and elusive, could only be the messenger of the gods. The name for Mars was perhaps the most obvious of all, since the red colour suggests blood, and Mars was the God of War. The Greek name for the War-God was "Ares", and

physical study of Mars is therefore known as "areography".

The last great astronomer of the ancient world was Claudius Ptolemæus, or Ptolemy, who died about the year A.D. 180. His most important book, which has come down to us by way of its Arab translation and is known by its Arab title of the *Almagest*, gives a complete summary of the state of knowledge at the end of Classical times. Nowadays it has become almost the fashion to decry Ptolemy and to claim that he was a mere copyist of other men's works, but this is unfair. He was a magnificent observer as well as being a mathematician of the first order, and astronomy owes him a great debt.

Unfortunately he made one fundamental mistake. Like most of the Greek scientists (though not all), he believed that the Earth must lie in the centre of the Universe, with the Sun, Moon, planets and stars moving round it in perfect circles. Yet even in those far-off times the apparent motions of the planets were known with considerable accuracy, and Ptolemy realized that these motions could not possibly be accounted for on the theory that the planets travelled round the Earth in circular orbits. Mars was particularly troublesome, and it was clear that something was badly wrong.

Ptolemy's remedy was to perfect a complicated system of "epicycles" and "deferents". An epicycle was a small circle, the centre of which—the deferent—itself moved in a circle round the Earth; and this was how he imagined that Mars and the other planets behaved. Discrepancies still remained, however, and more and more epicycles were introduced, until the whole system became hopelessly clumsy and artificial.

The reason why Ptolemy insisted upon perfectly circular orbits sounds strange to our ears. To the ancients

the circle was the perfect form, just as 7 was the mystical number, and to them it seemed impious to suggest that the heavenly bodies could move in paths of any other shape. Difficulties arose in the case of the Moon, whose apparent diameter varies, showing that its distance from the Earth is not constant; Ptolemy overcame this obstacle by supposing that although the Moon moved in a circle, the centre of this circle was not coincident with the centre of the Earth.

So matters remained for well over a thousand years. Most people were quite satisfied with Ptolemy's theory—after all, it was pleasant to believe the Earth to be a body of supreme importance—and it was not until the mid-sixteenth century that a jarring note was struck. Then, however, a Polish canon named Nicolaus Copernicus published a book in which he suggested removing the Earth from the centre of the planetary system, and putting the Sun there instead. Copernicus, like Ptolemy, was wedded to the idea of "perfect circles", and to explain the motions of the planets in the sky he was even reduced to bringing back epicycles, but at least he had taken the essential step.

The next astronomer of note was Tycho Brahe, a Danish nobleman, who was born at about the same time that Copernicus died, and lived until 1601. Unlike Copernicus, he was a poor theorist; he had absolute faith in the supreme importance of the Earth, and worked out a clumsy system which met with little or no support even at the time. But Tycho—also unlike Copernicus—was a magnificent observer. He had no telescopes, but he set up measuring instruments which were of remarkable accuracy, and he carried out work on the positions of the stars and planets which was of the highest quality. Rather fortunately, he paid great attention to the motions of Mars, as well as producing a star-catalogue which was

much better than any previous one. Shortly before his death he engaged as his assistant a young German mathematician named Johann Kepler, and when Tycho died the entire series of observations came into Kepler's hands.

Kepler's task was no light one. Using Tycho's planetary observations, he had to draw up a correct scheme of the Solar System, and decide once and for all whether the Sun or the Earth lay in the centre. Only a man with the spark of genius could have succeeded, but fortunately for science Kepler had that spark. Fittingly enough, he concentrated mainly upon Mars.

At first he could make no progress. Try as he might, he could not make Tycho's observations agree with any circular orbit, even by using epicycles. The positions very nearly agreed—but not quite, and Kepler knew that he could place absolute trust in the measurements left to him by Tycho. After years of labour he threw overboard all circular orbits and turned instead to ellipses. This time he was successful, and in 1609, the year in which Galileo made the first telescopic observations of the sky, Kepler was able to announce that "the planets moved round the Sun in ellipses, the Sun lying in one of the foci, while the other focus is empty". Henceforth the Copernican system reigned supreme.

Most people know that the planets, including the Earth, move round the Sun in elliptical paths, but it is not so generally realized that these paths are not very different from circles—in other words, the orbital eccentricity is slight. In round figures, the Earth has a mean distance from the Sun of 93,000,000 miles; at aphelion (greatest distance) it moved out to 94,500,000, while at perihelion (closest approach) the distance is reduced to 91,500,000. The variation amounts, therefore, to only about 3,000,000

miles, which is not a great deal. The orbital eccentricity amounts to no more than 0·017, and if the Earth's path were drawn to a scale of, say, 4 inches to the diameter of the orbit—so that it would just fit on to a page of this book—it would appear as virtually a circle.

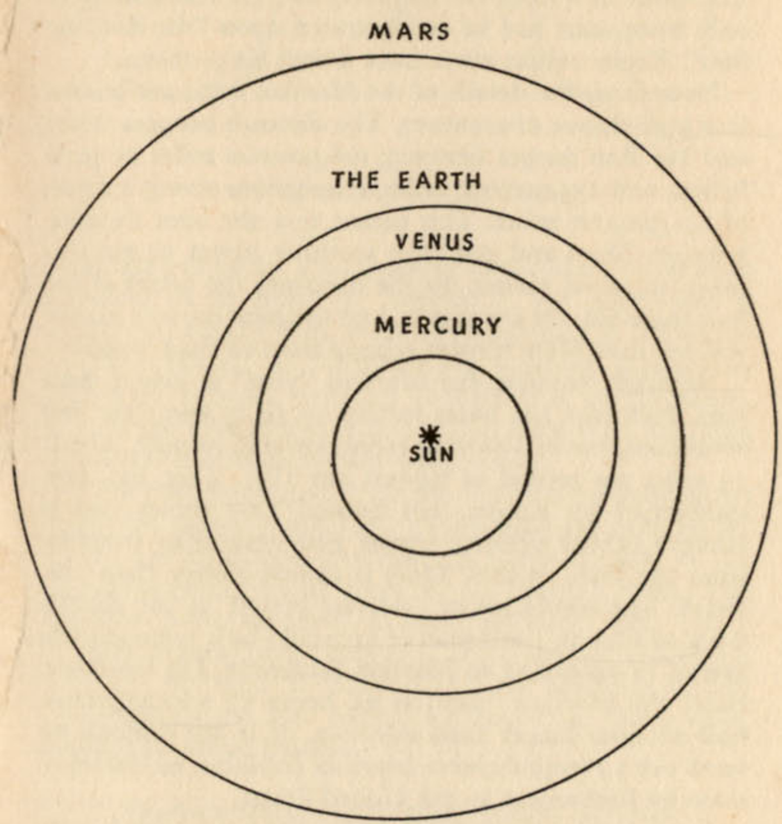


FIG. 1
The orbits of the four inner planets.
Distances and orbital eccentricities are correct

In the case of Mars, the eccentricity is 0·093, greater than that for any other planet apart from Mercury (excluding Pluto, of course, which was unknown until modern times). It was therefore lucky that Kepler selected Mars as the main subject for his investigations. The orbit of Venus, for instance, has an eccentricity of only 0·007, and had he concentrated upon "the Evening Star" Kepler might never have solved his problem.

Nowadays, the details of the Martian orbit are known to a high degree of accuracy. The distance between Mars and the Sun ranges between 128,500,000 miles at perihelion, and 154,500,000 miles at aphelion, giving a mean of 141,500,000 miles. This means that the least distance between Mars and our own world is about 34,000,000 miles, as noted earlier. In the diagram, the orbits of the four inner planets are shown, and the most cursory glance will tell that Mars is more remote from us than Venus.

Naturally enough, the Martian "year" is longer than ours. Not only has Mars further to go to complete one revolution, but it is moving more slowly in its path (about 15 miles per second as against our 18½). This, too, was established by Kepler. His Second Law shows that a planet's orbital velocity lessens with increasing distance from the Sun, so that Mars is always slower than the Earth. The revolution or "sidereal period" is 687 Earth-days, so that an Earthman of 21 would be a mere schoolboy of 11 according to Martian reckoning. On the other hand the Martian "day" is 24 hours 37 minutes, only half an hour longer than our own. It is not difficult to work out a comprehensive Martian calendar, as has been done by Richardson in the United States.

Another common factor between the two worlds is that the tilt of Mars' axis, 25·2 degrees, differs little from that of the Earth (23·5 degrees), so that the seasons follow the

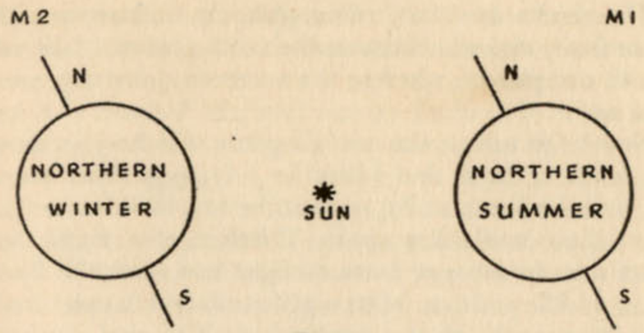


FIG. 2
The Martian Seasons. (Not to scale)

same kind of cycle. The diagram shows Mars in opposite positions in its orbit. At Position 1, the north pole is tilted towards the Sun, so that it is summer in the northern hemisphere; at Position 2 the southern hemisphere enjoys its summer, while it is midwinter in the north. Terrestrial seasons are caused in the same way, but with Mars there is an important modification.

With both Earth and Mars, the northern summer occurs when the planet is actually farthest from the Sun. So far as we are concerned, the effect is small, because of the comparatively circular form of the Earth's orbit. The Martian path, however, is more eccentric, and consequently the southern summer is much shorter and hotter than the northern. It followed that the southern winters are both longer and colder. Reckoned in Earth days, the details are as follows:

Northern summer or southern winter:	182 days
Northern spring or southern autumn:	199 days
Northern autumn or southern spring:	146 days
Northern winter or southern summer:	160 days

The results are easily observable. At midsummer, the icy or frosty cap which covers the south pole of Mars may vanish completely, whereas the northern polar cap never does so.

Now let us turn to the next diagram, which again shows the orbits of Earth and Mars. In July 1939 Mars was at M1 and the Earth at E1, so that the two worlds were just over 36,000,000 miles apart. The Sun, the Earth and Mars were in more or less a straight line, with the Earth in the middle position. Mars was therefore at "opposition", directly opposite to the Sun in our skies, and was well placed for observation.

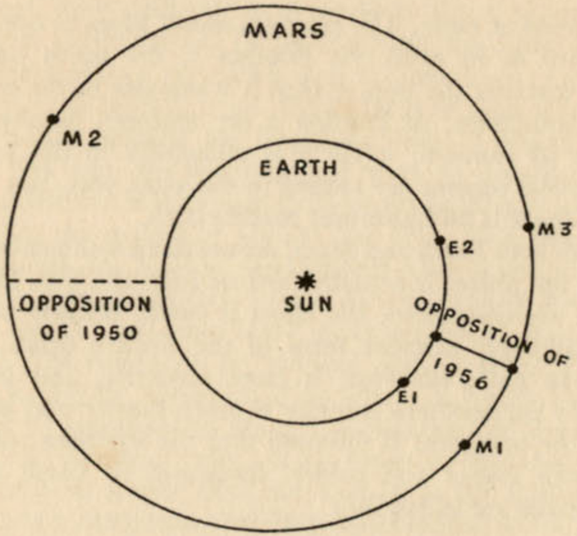


FIG. 3

Oppositions of Mars. At the opposition of 1939, Earth was at E1 and Mars at M1. The positions for the very favourable opposition of 1956 are shown by the heavy line; for the unfavourable opposition of 1950, by the dotted line

A year later, in July 1940, the Earth had completed one circuit, and had arrived back at E1—but Mars, moving more slowly in a large orbit, had not returned to M1. It had only reached M2, and was on the far side of the Sun, so that it was above the horizon during the daytime and was invisible at night—with the result that it was difficult to observe at all even with large telescopes. Before returning to opposition, it had to wait until the Earth had caught it up. This was not until October 1941, when the Earth was at E2 and Mars at M3.

At the 1939 opposition Mars was almost at perihelion. In the autumn of 1941, however, Mars was some way from perihelion, and the distance from us was never less than 38,500,000 miles. Again there was a lapse of almost two years before the next opposition, that of 1943, when Mars was even further from perihelion and the minimum distance from Earth was 50,600,000 miles. At the opposition of January 1946 the distance was 59,800,000 miles, while in 1948 it was as much as 63,000,000 miles. After 1948, however, things started to improve again, until at the opposition of 1956 Mars was at perihelion and at opposition almost simultaneously, just as had been the case in 1939.

Two facts emerge from this. First, oppositions of Mars take place at intervals of something like two years—more exactly, 780 days, the so-called "synodic period" (which, however, is only an average; it would be wrong to suppose that successive oppositions take place at intervals of exactly 780 days). Secondly, not all oppositions are equally favourable, and at present we are going through a "bad" period which will last almost up to the end of the 1960s. It may be useful to list the oppositions between 1960 and 1975, which are as follows:

Opposition date	Minimum distance from Earth, miles	Maximum apparent diameter, seconds of arc
1960 Dec. 29	56,200,000	15·4
1963 Feb. 3	61,800,000	14·0
1965 Mar. 8	61,800,000	14·0
1967 Apr. 13	56,200,000	15·4
1969 May 29	45,300,000	19·1
1971 Aug. 6	34,600,000	25·0
1973 Oct. 21	40,600,000	21·6
1975 Dec. 13	53,100,000	16·5

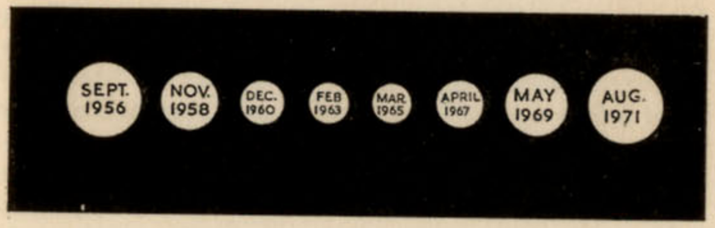


Fig. 4
Variation of size at opposition

European and North American astronomers always bemoan the fact that the most favourable oppositions take place when Mars is south of the celestial equator, so that observers in northern latitudes have the worst of it. The real trouble is that detailed work can be carried out only when the planet is within a few months of opposition, as otherwise the disk is too small to show much, and the "observation period" is naturally shorter with aphelic oppositions. One has to make the most of one's limited opportunities.

Mars, like the other planets, shines by reflected sunlight. At opposition the sunlit hemisphere is turned wholly towards us, and the disk appears circular, but this is not the

case when Mars is well away from opposition; part of the unlit or night-hemisphere is then turned in our direction, and the disk appears markedly gibbous, since the phase may be reduced to less than 90 per cent—as shown in the diagram. For obvious reasons, Mars never appears as a

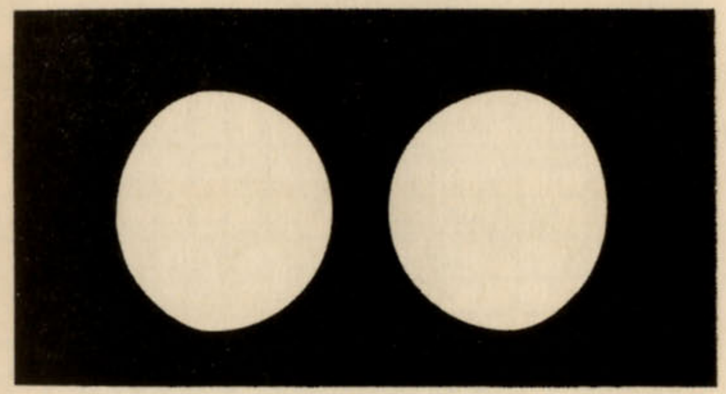
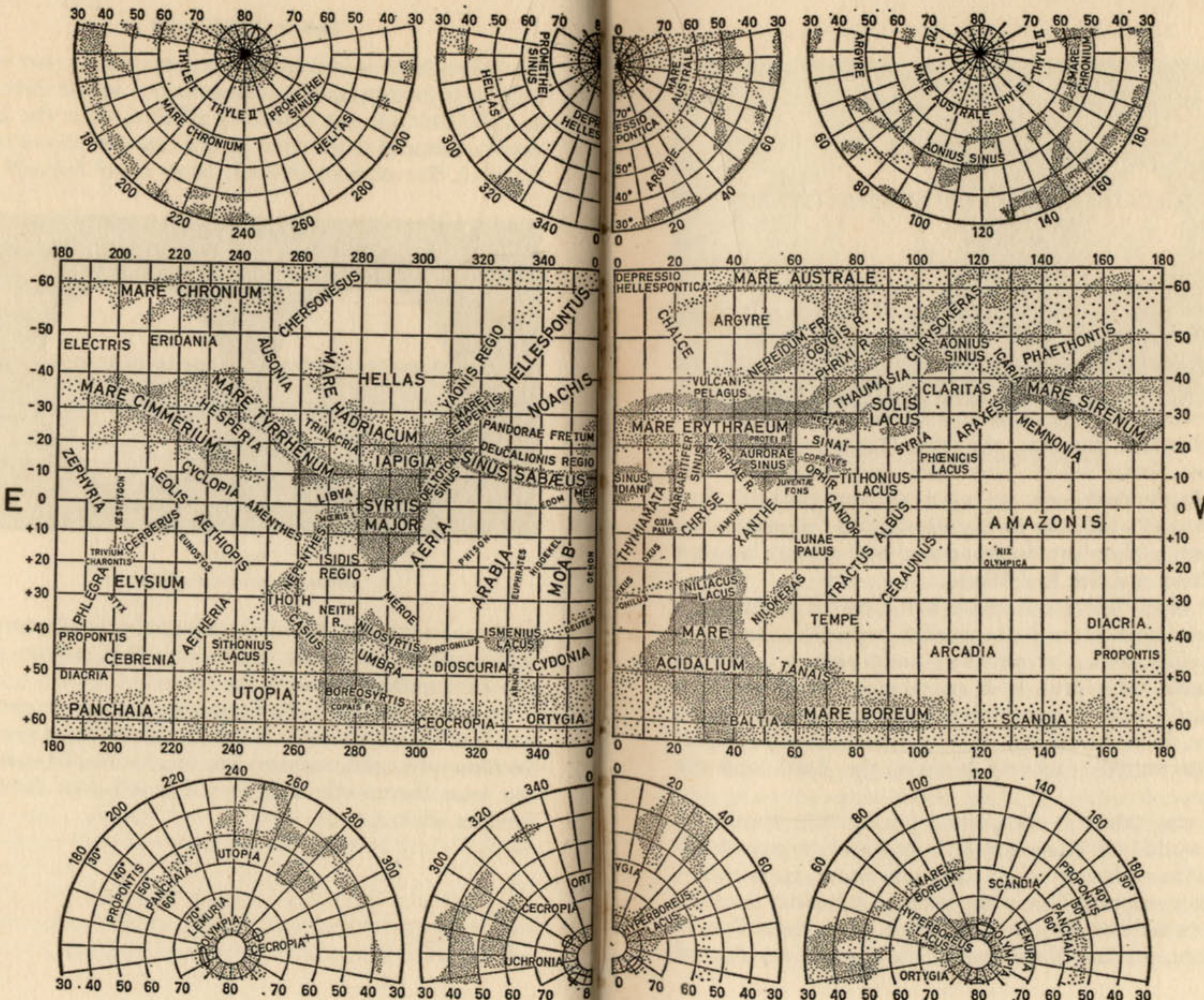


Fig. 5
Gibbous appearance of Mars

half or as a crescent. Of all the planets, only Mercury and Venus, which are closer to the Sun than we are, show phases resembling those of the Moon.

So much, then, for the movements of Mars; anyone who wants to take the matter much further must be prepared for some advanced mathematics. Meanwhile, let us turn to our main theme—the Red World as it is seen through a modern telescope.


E
W
MARE CHRONIUM
CHERSONESUS
ELECTRIS
ERIDANIA
AUSONIA
MARE HADRIACUM
HELLAS
YAONIS REGIO
HELLESPONTUS
NOACHIS
MARE CIMMERIUM
HESPERIA
MARE TYRRHENUM
TRINACRIA
MARE SERPENTIS
PANDORAE FRETUM
DEUCALIONIS REGIO
IAPIGIA
SINUS SABÆUS
ZEPHYRIA
AEOLIS
CYCLOPIA
LIBYA
SYRTIS MAJOR
DELTOTON SINUS
EDOM
AMENTHES
AETHIOPIS
CERBERUS
EUNOSTOS
TRIVIUM CHARONTIS
ELYSIUM
NEPENTHES
ISIDIS REGIO
AERIA
PHISON
ARABIA
EUPHRATES
HIDDEKEL
MOAB
PHLEGRA
STYX
THOTH
NEITH R.
MEROE
AETHERIA
PROPONTIS
CEBRENIA
SITHONIUS LACUS
CASIUS
NILOSYRTIS
PROTONILUS
ISMENIUS LACUS
DIOSCURIA
CYDONIA
UMBRA
DIACRIA
UTOPIA
BOREOSYRTIS
COPAIS P.
ARNON
PANCHAIA
CEOCROPIA
ORTYGIA
DEPRESSIO HELLESPONTICA
MARE AUSTRALE
CHALCE
ARGYRE
NEREIDUM FR.
OGYGIS R.
PHRIXI R.
CHRYSOKERAS
AONIUS SINUS
ICARIA
PHAETHONTIS
VULCANI PELAGUS
THAUMASIA
SOLIS LACUS
CLARITAS
MARE SIRENUM
MARE ERYTHRAEUM
NECTAR
ARAXES
MEMNONIA
PROTEI R.
AURORAE SINUS
SINAI
SYRIA
PHŒNICIS LACUS
COPRATES
OPHIR
TITHONIUS LACUS
SINUS MERIDIANI
MARGARITIFER SINUS
PYRRHAE R.
JUVENTAE FONS
THYMIAMATA
OXIA PALUS
CHRYSE
JAMUNA
XANTHE
CANDOR
LUNAE PALUS
TRACTUS ALBUS
AMAZONIS
CERAUNIUS
NIX OLYMPICA
NILIACUS LACUS
NILOKERAS
TEMPE
MARE ACIDALIUM
DIACRIA
ARCADIA
PROPONTIS
TANAIS
BALTIA
MARE BOREUM
SCANDIA
THYLE I
THYLE II
PROMETHEI SINUS
AONIUS SINUS
LEMURIA
OLYMPIA
CECROPIA
HYPERBOREUS LACUS
UCHRONIA

MAP OF MARS

CHAPTER TWO

TELESCOPIC OBSERVATION OF MARS

IN A telescope of fair size, Mars—when at its best—is a splendid object. The dominant hue of the disk is reddish-ochre, while darker patches may be seen here and there, and the pole is crowned with a white cap. A century ago it was believed that the ochre areas were deserts and the dark patches seas, with the polar caps made up of ice and snow. Had this been the case, the resemblance between Mars and the Earth would have been very striking indeed. Actually the dark areas are not seas—more probably they are tracts of what may be broadly termed "vegetation"—but even so there are distinct points of similarity between our planet and the Red World.

The chief differences between the two arise from the fact that Mars is much the smaller body. Its diameter is 4,219 miles, with a volume 0·15 and a mass 0·11 that of the Earth. Moreover, it is appreciably less dense than the Earth, and its gravitational pull is naturally much weaker. It is fair to say that in mass and dimensions, Mars is roughly mid-way between the Earth and the Moon.

We may take this comparison further. The Earth is a living world; the Moon is to all intents and purposes dead. Mars is in an intermediate state, and water, particularly, is in short supply. This is not because it is older than the Earth (whichever theory of the origin of the Solar System we adopt, it seems likely that all the planets were formed

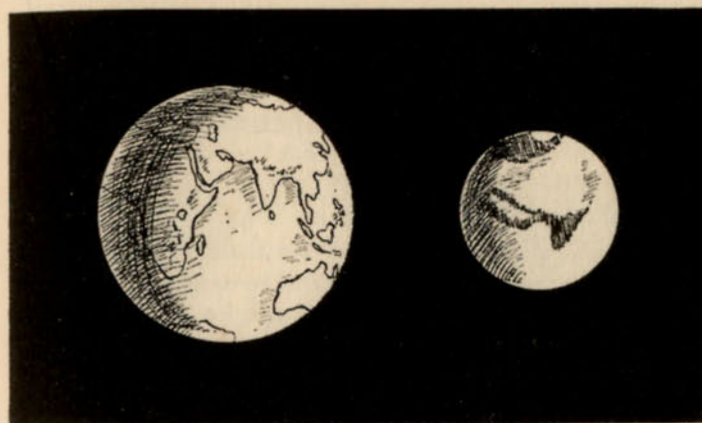


FIG. 6
Earth and Mars compared in size

at the same epoch), but because its smaller size has resulted in more rapid evolution.

Mars, like the Earth, is flattened at the poles, and the amount of compressions seems to be in the region of 1/190, which is rather more than in the case of our world. Up to now, we have had to admit that we have been rather in the dark as to the internal composition of the Martian globe. The Earth has a central core which may well be made up largely of nickel-iron, and there is no reason to doubt that Mars has a core of the same type, but it is probably smaller. The Earth's average density is 5·5 times that of water, but with Mars the value is only 3·9. The obvious deduction is that the "heavy" core is of lesser extent. Yet this is only a theory, and it may prove to be completely wrong.

The problem may well be solved by means of rocket research. So far as Mars is concerned, the Russians took the lead—as indeed they had done with artificial satellites. In 1962 they launched their probe *Mars I*, and although

they lost contact with it at a disappointingly early stage the experiment represented an encouraging start. One instrument carried on board the vehicle was designed to show whether or not Mars has a powerful magnetic field. If it has, then we may suppose that the Martian core is of the same kind as that of the Earth.

At the time when these words are being written (January 1965) one American rocket and one Russian rocket are on their way to Mars. All we can do is to await the results of their findings. Even if they fail, it will be most surprising if some rocket does not pass close to Mars within the next decade.

On the whole, we are more immediately concerned with the conditions which will be encountered on the surface. First, an Earthman on Mars would feel strangely light, so that a leap of 10 feet above the ground would be nothing remarkable. This, of course, is due to the relative weakness of Martian gravity, which is only 0·38 of that of the Earth. An explorer who weighs 14 stone at home will weigh a mere $5\frac{1}{3}$ stone on Mars. As his muscles will presumably be unaffected, he will seem to have acquired the strength of a Hercules—or more appropriately, perhaps, that of an Antæus.

Most people know what is meant by "escape velocity". Briefly, it is the starting velocity which a body would need to have in order to escape from its planet of origin. For the Earth, the value is 7 miles per second, but for Mars escape velocity amounts to only 3·1 miles per second. The most important result is that the Martian atmosphere is thinner than ours. Once, æons ago, Mars may have had a dense atmosphere similar to our own; but even if so, much of the original mantle has leaked away into space, and the present atmosphere is much too tenuous to be breathed by any Earth creature.

True "areography", the study of the physical features of Mars, may be said to have begun in the year 1840, when two German observers, Wilhelm Beer and Johann von Mädler, published a map of the planet. By then it had

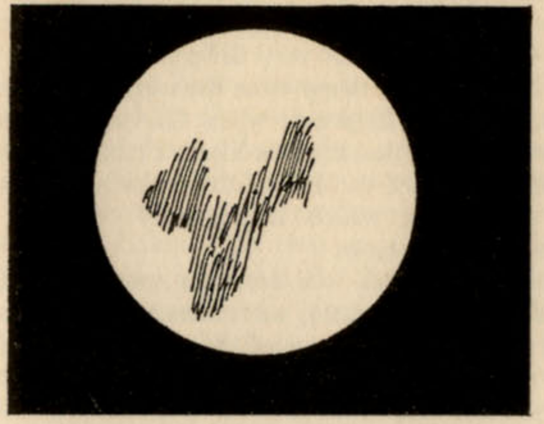


Fig. 7
The earliest surviving sketch of Mars, made on November 28, 1659, by Christiaan Huygens. The Syrtis Major is clearly recognizable

become generally known that Mars is basically similar to the Earth, though it was still thought that the dark patches must be seas. Beer and Mädler, best remembered nowadays because they drew up the first accurate chart of the Moon, had begun their studies of Mars at the perihelic opposition of 1830, but many drawings had been made before then and one or two are worthy of mention.

Galileo, the first telescopic astronomer of all time, could see almost nothing. This was not his fault; his tiny "optick tube" magnified only 30 times, so that he could not possibly have seen the disk markings, and it is

surprising enough that he was able to detect the phases. Christiaan Huygens, the Dutch observer who was the first to realize the true form of Saturn's ring-system, was more successful, and in 1659 he produced a drawing which clearly shows the V-shaped marking now known as the Syrtis Major. Huygens also stated that the rotation period of Mars was not very different from that of the Earth. At about the same time drawings were made by Robert Hooke in England, while Giovanni Cassini, an Italian who spent much of his life in France and became the first director of the Paris Observatory, glimpsed the white polar caps which instinctively conjured up a picture of ice and snow.

Little further work was done for some time. During most of the 18th century, astronomers were more concerned with the movements of the planets than with the planets themselves. The revival of interest came eventually, from 1780 onward, because of the work of two observers. There was William Herschel, who discovered Uranus and became the most famous astronomer of his time; there was also Johann Hieronymus Schröter, chief magistrate of the little German town of Lilienthal.

Schröter was an amateur, but an outstanding one. He is best remembered in connection with his studies of the Moon; he made drawings of many lunar features and measured the heights of some of the mountains much more accurately than his predecessors had done. Unfortunately he was not a good draughtsman, but so far as the Moon was concerned he made few serious mistakes, and he has never really received the credit which was his due (3). On the other hand, it is true to say that his observations of Mars were not of equal value. He believed that the dark patches were due to clouds, and therefore impermanent. Clouds do indeed exist in the Martian atmosphere, but

they are not usually conspicuous, and probably Schröter never saw a genuine one.

Herschel was a man of utterly different type. Hanoverian by birth, he came to England while still a young man and earned his living as an organist, spending his spare time on his hobby of astronomy. When he discovered the planet Uranus, in 1781, he became world-famous, and was appointed King's Astronomer to George III (not Astronomer Royal, by the way; that post was held by the Rev. Nevil Maskelyne). He made outstanding contributions to stellar astronomy, and was the first man to draw up an approximately correct theory of the shape of the star-system or Galaxy. As well as being the greatest observer of the century he was also the greatest telescope-maker, and finally produced a giant reflector with a focal length of 40 feet, though it was not so successful as had been hoped.

Herschel, then, was concerned mainly with the stellar system and the structure of the Galaxy; planetary studies were only incidental. He made various drawings of Mars and established that the rotation period was 24½ hours; the value which he gave (24 hours 39 minutes 22 seconds) was only two minutes too long. He also observed the polar caps, stated that Mars has an appreciable atmosphere, and measured the inclination of the axis of rotation. In addition he noted colour changes which he thought must be due to seasonal effects. However, he made no attempt to construct a chart of Mars. The credit for this must go to Beer and Mädler, who published their map eighteen years after Herschel's death.

Since 1840 Mars has been a favourite telescopic object, and has probably received at least as much attention as all the other planets put together. Even a small instrument will show some of the markings when conditions are

favourable, and Mars has always been regarded as particularly fascinating simply because it seems able to support at least some forms of life.

One desirable introduction was made by R. A. Proctor in 1867, who produced a map in which the various surface features were named. His nomenclature was followed by others—including another Englishman, N. E. Green, whose chart was probably better than Proctor's. The names are given in the diagram, which represents Green's chart transferred to a Mercator projection. The basic scheme was to honour astronomers of the past and present, as had been done with the craters of the Moon, so that the map contained Mädler Continent, Cassini Land, Beer Continent, Airy Sea and so on. As a reference point for the zero meridian of longitude, Green followed Proctor in selecting a small feature which was known as Dawes' Forked Bay in honour of the English amateur W. R. Dawes. The V-marking drawn by Huygens so long before was christened the Kaïser Sea, after a German astronomer who had drawn a map of Mars in 1864.

The "personal" names for the lunar craters have survived, and are still in use, but Proctor's similar proposal for Mars lasted for only a short while. In 1877 Mars was excellently placed, and G. V. Schiaparelli, at Milan, was able to draw up a map which superseded all the earlier attempts. He also took the opportunity to revise the names; thus Proctor's Kaïser Sea became the "Syrtis Major", while the old Beer Continent is today divided into three areas known as Æria, Arabia and Moab. Dawes' Forked Bay was retained as marking the zero longitude, but was rechristened Sinus Meridiani. Schiaparelli's system prevailed, though recent proposals have been made to amend it yet again.

The year 1877 was memorable in "Martian history"

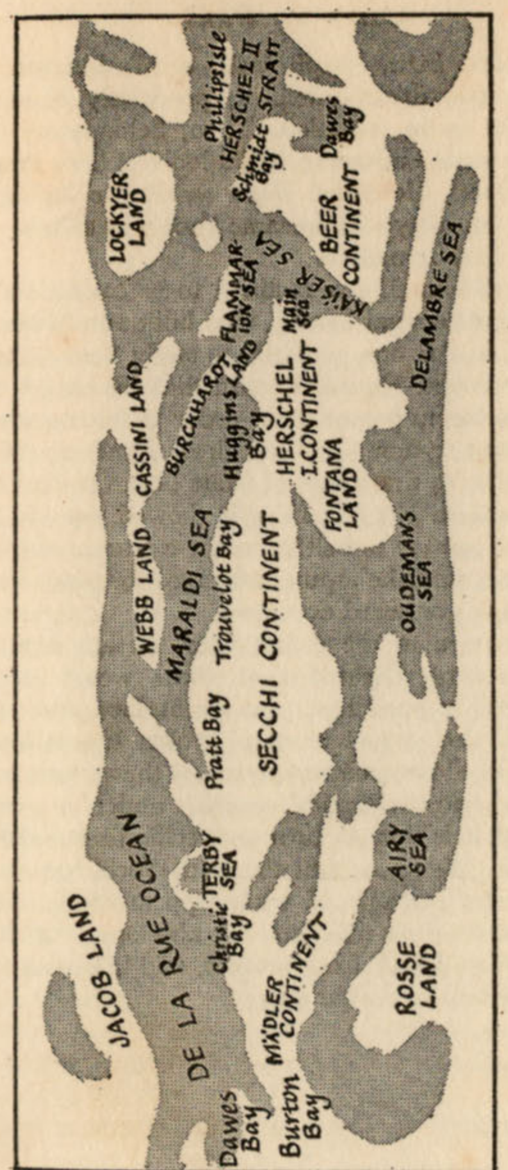


Fig. 8

Old names of Martian features, as given by N. E. Green. The names, with their modern equivalents, are listed in Appendix IV

for two events. First, Asaph Hall, at Washington, discovered the two dwarf satellites; previously Mars had been thought to be moonless. Then, Schiaparelli drew attention to some curious artificial-looking lines crossing the ochre tracts. He called them *canali*, the Italian for "channels", but they soon became known as canals—and canals they have remained.

Schiaparelli himself was inclined to be cautious about his canals, but Percival Lowell, who built an observatory at Flagstaff, in Arizona, specially to study them, had no doubts whatsoever. He was certain that the canals were made by intelligent engineers in order to form a planet-wide irrigation system, and he drew hundreds of the curious streaks, so that maps of Mars began to look very unnatural indeed. Not surprisingly, Lowell was attacked by those who refused to believe in the existence of intelligent Martians, and the arguments raged for many years; echoes of them are heard even now.

We will return to the canals later. At any rate, the whole controversy ensured that Mars would not be neglected, and interest has been maintained ever since, though until the arrival of space-probes it was largely amateur. It would be pointless to list all the various maps, observations and theoretical papers under a general heading, and it is time to turn to specific features of the Martian disk. We know that the Red World has atmosphere, "deserts", tracts of what appear to be living organisms, and a little moisture. We also know that it has polar caps of an icy or frosty nature, and it is with these caps that we will begin our survey.

CHAPTER THREE

THE POLAR CAPS OF MARS

IN 1666, the year of the Fire of London, Mars was observed by the Italian astronomer Giovanni Cassini, later Director of the Paris Observatory. Like Huygens some time earlier, Cassini saw the Martian markings well enough to draw them. He also saw that the polar regions were covered with some sort of bright, whitish deposit which looked, at first sight, remarkably like snow. Whichever pole happened to be tilted towards the Earth showed this covering, and the resemblance between the Martian polar regions and those of our own world seemed too close to be due to mere coincidence.

An earlier drawing, made by Huygens in 1656, is said to have shown indications of the caps. So far as I have been able to discover, this drawing is no longer in existence, but in any case the question of priority does not matter; it is enough to say that the caps were definitely recorded during the seventeenth century. Subsequently they were seen by many other observers, and in 1719 Giacomo Maraldi, also Italian—in fact, a connection of Cassini's—recorded that the northern and southern caps were not exactly opposite to each other upon the Martian globe. From this, it seemed likely that—as on Earth—the coldest regions are not exactly at the poles, though Maraldi himself offered no explanations and did not even guess as to the nature of the white areas.

Next to study the polar caps was William Herschel,

who paid some attention to Mars between 1777 and 1784. Herschel realized that the caps are at their largest during the Martian winter and shrink steadily during the spring and early summer, reaching their minimum size in late summer. He accordingly supposed that they were made of ice and snow. Probably the idea did not originate with Herschel, but he seems to have been the first to record it as a definite theory, and in any case it appeared to be self-evident. The Earth has polar caps of this type; why should not Mars, fundamentally an earthlike planet, show similar features?

Herschel's suggestion was made in 1784. Strange to say, it met with a good deal of opposition in after years, and during the present century two British scientists, A. C. Ranyard and Johnstone Stoney, put forward the alternative theory that the caps were not made of watery material at all, but of solid carbon dioxide—the "dry ice" to be seen in the freezing compartment of an ice-cream vendor's barrow. This idea was hotly challenged by Percival Lowell, who devoted a lifetime to the study of Mars and who believed that he had seen signs of intelligent activity upon the surface. Lowell was convinced that the caps must be snowy, but it was not until 1948 that the question was finally cleared up by means of that second great astronomical weapon, the spectroscope.

Whereas a telescope collects light, a spectroscope analyzes it. A ray of "white" light is not so simple as it might seem; it is highly complex, made up of a combination of light-rays of different wavelengths. The idea of light having a wavelength is unfamiliar to some people, and it is difficult to give a correct everyday analogy, but perhaps the best is to throw a stone into a calm pond and watch the ripples spreading outward; the wavelength is then the distance between one crest and the next. Of

course, light is not a material wave, and the analogy is rough and imperfect, particularly as the wavelength of light is extremely short, but it may serve to show the basic principle.

The light from Mars may be analyzed spectroscopically, and the result is most informative. After a number of tests, G. P. Kuiper, at the McDonald Observatory in Texas, felt confident enough to state that "the Mars polar caps are not composed of carbon dioxide, and are almost certainly composed of H_2O frost at low temperature, much below 0° Centigrade" (4). Kuiper's work was followed up by Audouin Dollfus, in 1950, at the Meudon and Pic du Midi Observatories in France. The agreement was excellent, and Dollfus, too, was sure that the caps were of any icy or frosty nature (5).

A Russian astronomer, the late G. A. Tikhoff, who has investigated an entirely new field of research which he calls "astobotany" and which will be described in Chapter Four, has suggested that the caps are no more than slight deposits of hoar-frost. The official definition of hoar-frost is "thin ice crystals in the form of scales, needles, feathers or fans". Whether Tikhoff is correct or not remains to be seen.

Before the period when delicate spectroscopic investigations were possible, Lowell and others had tried to prove the watery nature of the caps by visual observation. Lowell summed matters up when he wrote (6): "At pressures of anything like one atmosphere or less, carbon dioxide passes at once from the solid to the gaseous state. Water, on the other hand, lingers in the intermediate stage of a liquid. Now, as the Martian cap melts it shows surrounded by a deep blue band which accompanies it in its retreat, shrinking to keep pace with the shrinkage of the cap . . . This badge of blue ribbon about the melting

cap, therefore, shows conclusively that carbon dioxide is not what we see, and leaves us with the only alternative that we know of: water."

From a theoretical point of view Lowell's argument is perfectly sound. Everyone knows that the caps do shrink rapidly with the onset of summer, and no carbon dioxide deposit could possibly show a deep blue band such as that described by Lowell. Even a temporary sea is unlikely upon an arid planet such as Mars, but there seemed to be no objection to the idea that the dark band was due to temporary moistening of the surface. However, other authorities cast grave doubts upon the actual existence of the band. Schæberle, for instance, stated categorically (7) that it was an optical effect due to contrast between the brilliant poles and the dimmer areas nearby. This was also the opinion of E. M. Antoniadi, who wrote (8) in 1930: "The illusory character of the band in question was first recognized by Schæberle. I have confirmed this theory by observing that it does not follow the laws of perspective, and that it cannot be photographed."

As to the apparent existence of the dark band, there can be no doubt at all; it can be seen with a very small telescope. Moreover, it can be extremely prominent; for instance I do not think that I have over-emphasized it in the drawing given here (facing page 65, upper left-hand); not even the most casual observer could have overlooked it. On the other hand we know that the human eye is easily deceived and that it is dangerous to jump to any hasty conclusions.

Contrast must certainly play a part, but after making a long series of observations at Le Houga Observatory in 1939, G. de Vaucouleurs came to the conclusion that even when all optical effects had been taken into account, the area of the band was still darker than might have been

expected—and that the band itself was, therefore, real (9). The same opinion was expressed by Dollfus (10). Kuiper was even more emphatic, and wrote as follows (11): "I observed it with the 82-inch reflector under excellent conditions in April 1950, and found it black . . . The rim is unquestionably real; its width is not constant, and its boundary is irregular."

It is very probable that Lowell exaggerated the blue colour of the band. However, all the evidence shows that it is something more than a straightforward contrast effect, and temporary marshiness seems to be the only answer.

Yet we cannot go back to the original idea of a short-lived polar sea. Occasional pools of water are as much as we can ever expect to find, and even these are dubious. The reason is easy to see. The polar caps are remarkably thin, and in no way comparable with the tremendous icy layers which cover our own Greenland and Antarctica. De Vaucouleurs has estimated (12) that their thickness can hardly be more than a couple of inches at most. Other authorities are inclined to increase this somewhat, but if we could melt all the polar ice at once the resulting volume of water would hardly fill a lake the depth of Windermere and the size of Wales.

The main proof of this extreme thinness is the rapid shrinkage of the caps during the Martian spring. At its greatest extent the southern cap may cover an area of well over 4,000,000 square miles, yet later in the same Martian year it shrinks to a tiny patch; in 1894, indeed, Lowell and Douglass at Flagstaff and E. E. Barnard at the Lick Observatory were astonished to find that it disappeared altogether. This state of affairs is highly unterrestrial. It would indeed be surprising to find that Antarctica had suddenly lost its snowy mantle.

As we have seen, the southern summer on Mars is

shorter but hotter than the northern, while the winter is both longer and colder. This difference is reflected in the behaviour of the caps. The northern cap does not vary in size so greatly as its counterpart; it cannot cover such a tremendous area, but neither has it ever been known to vanish completely, though it can become too small to be seen without a telescope of considerable power.

It may be misleading to say baldly that the Martian caps "melt" in the spring. Under some conditions of temperature and pressure, it is possible for a solid to "sublime", e.g. pass directly into the gaseous state without passing through the liquid condition at all. On Mars, the atmospheric pressure and temperature are much lower than on Earth, and a certain amount of sublimation must occur. Some authorities have even suggested that sublimation is the main mechanism in the seasonal decrease of the polar caps.

The southern pole of Mars is tilted towards us during perihelic oppositions of the planet. This is rather fortunate, as our best views are therefore of the larger and more interesting of the two caps. If the season is a normal one, the cap is large and prominent during the Martian winter, extending as far towards the equator as latitude 55 to 60 degrees; a terrestrial cap of similar relative size would extend down to South Scotland. As warmer weather arrives the cap begins to shrink. At first the decrease is so slow that it is difficult to detect, but gradually it becomes more rapid, until at the maximum period of shrinkage the change in size may be observed from night to night. Now, too, Lowell's Band appears; the fact that it cannot usually be seen much before the period of fastest decrease is another argument against Schæberle's contrast theory.

As the cap shrinks, its outline becomes less regular.

Two dark rifts occur, one known as the Rima Australis and the other as the Rima Angusta; they are seen on every occasion when the decreasing southern cap is well placed for study, always in the same positions and always at about the same date in the Martian year. Subsequently the outline of the cap becomes so distorted that a bright white area is left behind, showing up as distinct from the main mass. It is known as the Novissima Thyle—this being the name given by Schiaparelli, in 1877, to a feature in the polar zone which more or less corresponds in position to the isolated white patch, though to my mind the identification is somewhat dubious.

The Novissima Thyle is a most interesting object. In 1911, observers of the Mars Section of the British Astronomical Association—at that time directed by Antoniadi—saw it well before it was left behind in the general shrinkage, appearing in the guise of a sparkling white spot well within the main cap (13). It then showed up as a brilliant promontory before the principal cap shrank away and left it behind. At a later period in the seasonal cycle, the Novissima Thyle itself usually breaks up into small white dots before vanishing; the main cap becomes very small, and towards the end of the period of decrease Lowell's Band fades and disappears.

As the Martian autumn draws on and winter approaches, the cap becomes hidden by a whitish overlying haze which can sometimes become prominent enough to be mistaken for the surface cap itself. The winter growth of the cap is therefore hidden from us, partly because of the haze and partly because Mars has by then drawn too far away from us to be properly observed. By the time that the Red World swings near once more, the haze has cleared leaving the cap again bright, regular and extensive.

These changes in the southern cap are more or less duplicated in the far north, though in less extreme form. Here, too, we have a detached area—Olympia, the northern equivalent of the Novissima Thyle—separated from the main white zone by a rift known as the Rima Borealis; here too we have the Lowell Band, the irregular shrinking, and the hazy veil which masks the growth of the cap after minimum size has been reached.

There seems no reason to doubt that an icy or frosty deposit will persist longer on high areas, just as is the case on Earth, and it may well be that regions such as Olympia and the Novissima Thyle are true plateaux, though we cannot be sure. Mars is not a mountainous world, and there are no great ranges of peaks, but there is no reason to suppose that the surface is completely flat. Neither are the plateaux necessarily confined to the polar regions—for instance it has been suggested that a feature known as the Nix Olympica, discovered by Schiaparelli as long ago as 1879, is an isolated peak or table-land, since it often appears as a brightish spot. If this interpretation is correct, the "rimæ", or rifts, may be valleys.

It would be difficult to over-emphasize the importance of the polar caps in Martian study. The caps are bound up with the whole seasonal cycle of the planet. If we are right in thinking that the darker areas are due to living organisms, it is only reasonable to assume that Martian life is largely regulated by the waxing and waning of the polar mantles. Though their development is sometimes faster and sometimes slower than normal, they do not change basically even across the centuries. The brilliant caps which we see at the present time do not differ from those which fell under the eagle eye of Giovanni Cassini almost 300 years ago.

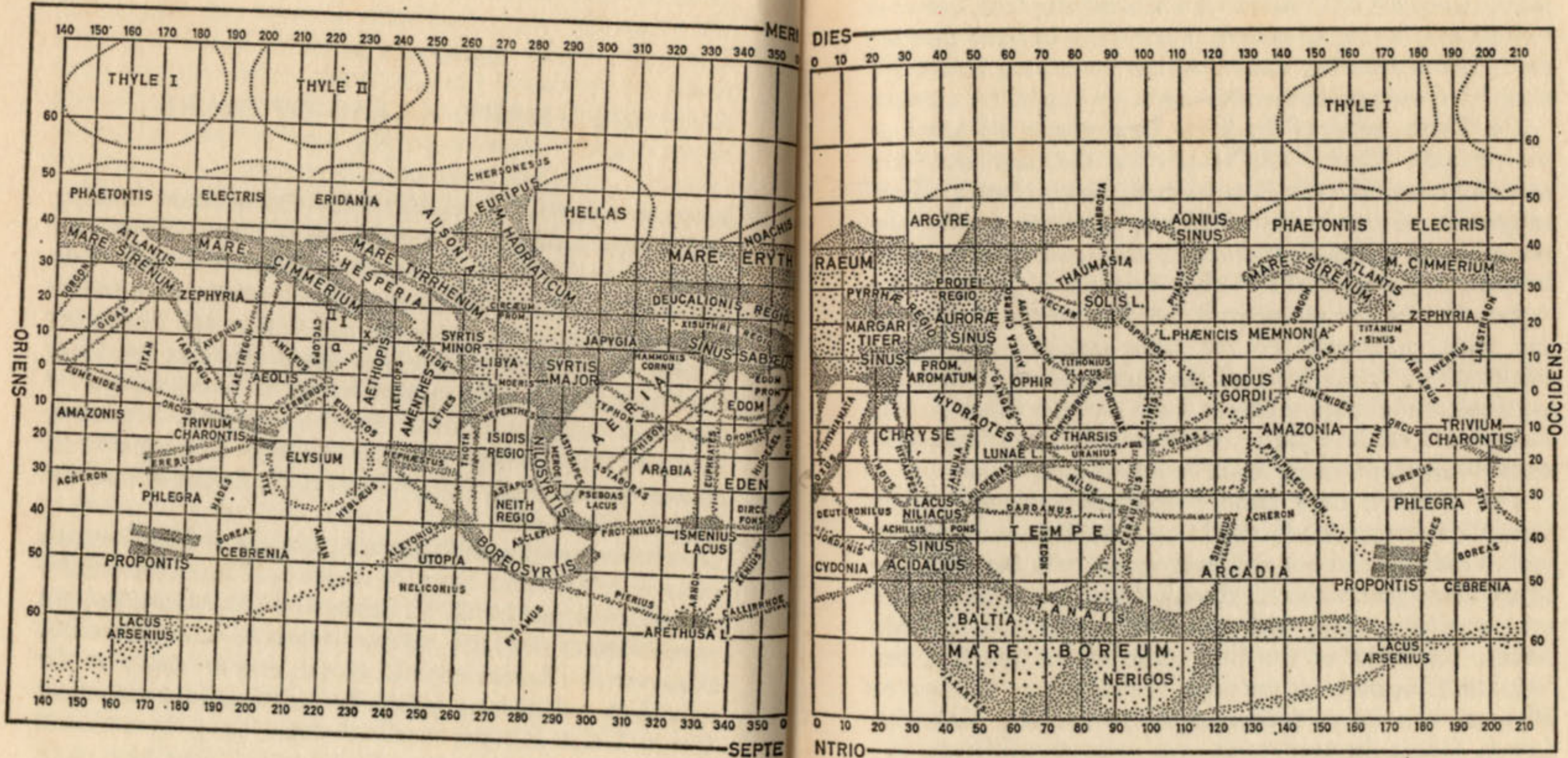
CHAPTER FOUR

THE DARK AREAS OF MARS

SPREAD ACROSS the reddish-ochre disk of Mars, bearing at first sight a distorted resemblance to a map of our own world, may be seen the darkish patches which were originally thought to be sheets of open water. As we have noted, Huygens was probably the first to see them; his famous drawing of 1659 shows one prominent marking, the Syrtis Major, quite unmistakably. He was followed by observers such as Cassini, Hooke, Maraldi, Herschel, Beer and Mädler, and then by a host of mid-nineteenth century astronomers such as Dawes, N. E. Green and the Rev. T. W. Webb.

As instruments were improved, so maps of Mars became more reliable. After 1877, in which year intensive studies were carried out by G. V. Schiaparelli at Milan, the old nomenclature for the surface features was discarded. Schiaparelli's names are still in use, and are given in the official map drawn up by the International Astronomical Union, which is reproduced on pages 24–5. It is rather interesting to compare the old names with the new ones.

One important point is that in all maps of Mars, south is at the top. All astronomical drawings and photographs are orientated in this way. This is because all common telescopes give naturally inverted images. For terrestrial use this is corrected by the insertion of extra lenses. Each time a light-ray passes through a lens, however, it becomes slightly enfeebled; while this does not matter in the



MARS 1883-84

FIG. 9 Schiaparelli's Observations

least if one happens to be looking at ships or landscapes, it matters a great deal when we are studying faint celestial objects and trying to collect every scrap of light that we can. Astronomically, therefore, the correcting lenses are simply left out and south remains at the top of the picture.

On Earth, most of the great land-masses lie north of the equator. Mars is all "land", but the dark areas are spread across the disk in a pattern which gives a vague suggestion of our own continents. Needless to say, the resemblance is rough and not in the least significant. A brief description of the surface features is given in the Appendix; for the moment, it will be enough to mention the most prominent of the dark patches—the Syrtis Major (from which lead off the Sinus Sabæus and other portions of the main southern belt) and the Mare Acidalium, north of the equator, which also is clearly visible in a small telescope when Mars is well placed.

The southern dark band is sometimes known as the Great Diaphragm, while the Mare Acidalium is associated with a less conspicuous and less regular belt. Between, the ochre areas predominate, though here and there can be seen smaller patches with romantic names such as Solis Lacus, the Lake of the Sun. One of the patches, the Trivium Charontis on the edge of the "desert" known as Elysium, can be very prominent; so can the Tithonius Lacus, as was the case during the opposition of 1960–1.

So much for the actual distribution of the sombre areas. What of their nature? Can we be sure that they are not oceans, or at least ocean beds?

The first challenge to the water theory came as long ago as 1863, when Schiaparelli remarked that the dark areas did not reflect the Sun's image as sheets of water ought to do. (More recently, the Russian astronomer Fesenkov has calculated that any water surface with a diameter greater than 300 yards ought to betray itself in this way, but nothing of the kind has ever been observed.) Fifteen years later Liais, a French observer who did most of his best work in Brazil, put forward the alternative theory that the dark areas were not seas at all, but patches of vegetation. At first his ideas attracted little or no attention, but before long fresh evidence came to hand. W. H. Pickering, of the United States—one of the few professional astronomers who specialized in planetary work; he died only in 1938—detected details on the dark patch known as the Mare Erythræum, while Lowell and Douglass established that other dark areas also showed a good deal of fine structure. Moreover, theoretical investigations proved that the thin Martian atmosphere contained very little water vapour, which did not fit in at all well with the idea of extensive oceans. Before the end of the nineteenth century, the whole "sea theory" had become hopelessly untenable.

Oceans being rejected, it was natural to turn to Liais' idea of great tracts of vegetation. Lowell and Pickering strongly supported it, and today it is almost, if not quite, established. Let us examine the evidence for and against it.

First, however, what is meant by "vegetation"? In some ways the word is misleading, since it implies a similarity with Earth-type plants; yet Martian conditions are entirely different, and any life there may well have developed along unfamiliar lines. It would be better to substitute "living organisms". For the moment, however, there is no harm in referring to vegetation—so long as we remember that the term is being used in its broadest sense.

Evidence may be drawn from the seasonal cycle bound up with the shrinking of those all-important features, the polar caps. Over eighty years ago Liais noticed that when

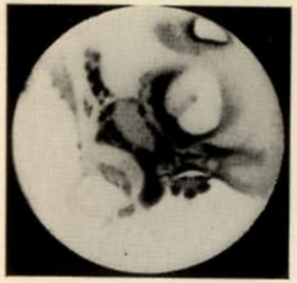
a cap starts to shrink, so presumably releasing a certain amount of either water or water vapour, the dark areas nearby seem to wake to life. From being greyish and faint, they darken and harden (14) as though being revived by the moisture; and what de Vaucouleurs has described as a "wave of darkening" (15) spreads further and further towards the equator. It is not perfectly regular. Some areas are much more responsive than others, and the Trivium Charontis, mentioned above, always appears dark whatever the state of the seasonal cycle. Local conditions must play their part, and C. Tombaugh, the American astronomer who made the actual discovery of the planet Pluto in 1930, believes the Trivium Charontis to be a depressed area several thousands of feet below the level of the surrounding desert.

As the "wave of darkening" spreads, certain alterations take place in the shapes of some of the prominent dark areas—always at or about the same time in the Martian year. During the southern spring and summer, for instance, the Syrtis Major is comparatively narrow, but with the onset of autumn it begins to spread eastwards, encroaching on the regions known as Libya and Mœris Lacus, while the neighbouring Pandoræ Fretum is obscure during the Martian equivalents of February and October, darkening perceptibly in November and becoming very conspicuous during the Martian January. According to de Vaucouleurs, who has devoted a great deal of time to the problem (16), these and other alterations occur so regularly that they can be predicted, and they seem certainly to be bound up with the shrinking of the polar caps. Vegetation might be expected to behave in such a way.

Few observers have the chance to investigate the phenomenon in detail, since a really large telescope is

Mars, photographed in red light, 200-inch Reflector, Mount Wilson and Palomar Observatories

Mars, photographed in blue light, 200-inch Reflector, Mount Wilson and Palomar Observatories

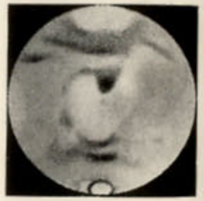


Drawing of Mars in 1909
by E. M. Antoniadi,
33 in. O.G., Meudon

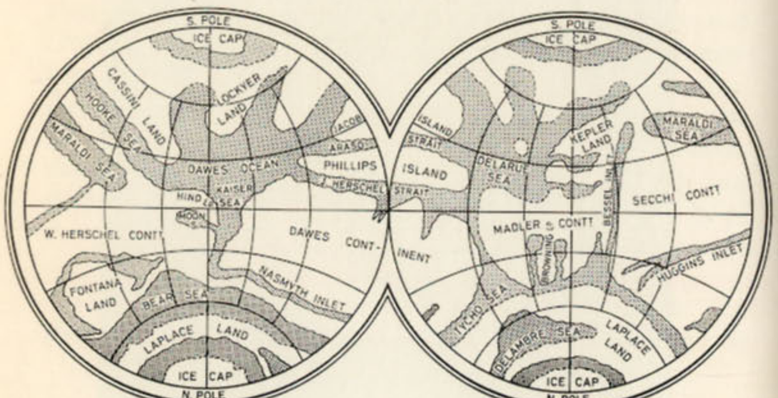
The North Polar Cap of Mars,
1935, May 1.
E. M. Antoniadi, 33 in. O.G.

Mars:
Rev. T. E. R. Phillips,
1920, May 14,
8 in. O.G.

Mars:
Rev. T. E. R. Phillips,
1935, April 22,
18 in. Refl.



Mars:
Rev. T. E. R. Phillips,
1935, April 14,
18 in. Refl.



A chart of Mars laid down on the Stereographic Projection
by R. A. Proctor from drawings by Dawes

needed; with smaller instruments Mars can only be well observed when it is close to opposition, so that the period of watch is limited to an inadequate couple of months or so. I have been able to follow the progress of the cycle with the help of the 33-inch refractor at the Observatory of Meudon, near Paris (the telescope used by Antoniadi for most of his planetary work), but the modest 12½-inch reflector at my own observatory is not powerful enough. Most amateurs are, in fact, limited, and they cannot provide so much useful information as with—for instance —Jupiter. Now that the first Martian probes have been launched, it is likely that studies of the planet will be made more regularly at official observatories, which ought to yield much more information before long.

Superimposed on the seasonal alterations are the irregular changes, which cannot be predicted, but which are sometimes striking enough to make whole areas virtually unidentifiable. They are of two types. Sometimes a dark area will spread out on to the neighbouring ochre tracts, as though the living organisms were gaining a temporary foothold on the less fertile deserts before dying away again; several cases of this sort were seen during the favourable opposition of 1939. Other changes are much more rapid. Perhaps the best example of a variable area is the Solis Lacus (Lake of the Sun), which may be found in the southern hemisphere in the region of the great ochre tract marked on the map as Thaumasia.

Normally the Solis Lacus is an elliptical area some 500 miles long and 300 miles wide, with its longer axis lying east to west. It was thus drawn by Maraldi in 1704, and remained almost unchanged (so far as we know from the incomplete records) until 1926, when the Rev. T. E. R. Phillips, a very experienced observer, found to his surprise that the shape had changed—the longer axis now

lying in a north-south direction. Later in the year Antoniadi, using the Meudon 33-inch refractor, drew the Lacus as three separate patches, the central one separated from its companions by a dusky "bridge". By 1930 all was normal once more, with the longer axis back in its old east to west direction; but in 1939 further disturbances took place, and at one time the Lacus was made up of a number of small dark spots contained in a generally dusky area. Clearly something unusual was taking place. Generally, the feature is beyond small telescopes, but at times it can attain prominence. For instance, using an 8½-inch reflector on 11th January 1961, I recorded it as a very dark, small, circular patch, more pronounced than the Trivium Charontis.

The Solis Lacus is not unique in showing alterations of this sort. Equally major disturbances took place in 1939 north of the Mare Cimmerium, and it was not until 1948 that the whole area changed back to its original aspect. It cannot be denied that changes of such a kind could be easily explained by the spread and subsequent decay of vegetation.

Colour changes have also been noted. There is, however, no obvious analogy with conditions on Earth; instead of turning green in summer, the Martian areas tend more to change from faint bluish-green to a brownish tint. This was pointed out by Lowell (17) in 1894, who said that in that year the change to brown occurred during the spring in middle latitudes, though in 1903 it did not take place until early winter (18). Later, Antoniadi found that in general, the Syrtis Major changed to brown in the early summer (19). I can make no personal contribution to the discussion. It may be that my eyes are not colour-sensitive, or it may be that I have not made enough observations with a large reflector (refractors, of course,

are always unreliable for visual colour estimates); at any rate I have to confess that the strong hues so often shown on drawings of Mars elude me completely. I can see that Lowell's Band, at the edge of the polar zone, can appear faintly bluish, and I have suspected very fugitive bluish or greenish casts in the main dark areas, but without any certainty. It seems that, at least, some observers tend to show the colours as much more violent than they really are.

In 1952 a simple but ingenious argument was put forward by E. J. Öpik, of the Armagh Observatory (20). As Öpik pointed out, windspeeds on Mars can be quite appreciable, and it is highly probable that the "deserts" are covered with dusty material, so that much of this dust must be blown on to the dark areas. If the dark patches were not due to something which grows, and can therefore push the dust aside, it would take only a few centuries for them to become completely covered, so that Mars would assume a monotonous, uniform hue. We know that this does not happen. We have observational proof that the dark areas have existed in their present form for more than 300 years, and there can be little serious doubt that they are essentially permanent. So far, no counter to this argument has been forthcoming.

As so often in astronomy, the decisive evidence seems likely to come from observations made with the aid of the spectroscope. If we could detect indications of organic matter in the spectra of the dark areas, we would have the answer to our problem; and many attempts have been made.

At first, efforts were made to detect chlorophyll, the green colouring matter of so many Earth plants. The results were negative. Chlorophyll looks green because the green light is not absorbed, but reflected back again;

it also reflects "infra-red" wavelengths, which cannot be seen visually, but which may be recorded on infra-red photographs. It was reasoned, therefore, that if the Martian areas contained chlorophyll, they should appear bright when photographed in infra-red. Disappointingly, they still looked dark. Did this mean that there was no chlorophyll, and therefore no vegetation? V. M. Slipher, of the Lowell Observatory, who made the first serious investigations in 1924, was suitably cautious (21); but the result was certainly not encouraging.

Yet the negative evidence was by no means conclusive. First, there is no need to suppose that all forms of vegetation should show evidence of chlorophyll. G. A. Tikhoff, of the U.S.S.R., justly argued that it would be only reasonable to compare the spectra of the Martian dark areas with the spectra of plants living in very cold regions of the Earth, such as the Siberian tundra; and after a long series of experiments, he came to the conclusion that the spectra were not so very dissimilar (22). It is fair to say that while the presence of chlorophyll would have more or less proved the existence of what may be termed plant life, the absence of detectable chlorophyll did not necessarily disprove it.

Then, in 1959, W. M. Sinton, in the United States, was able to produce something much more definite. In the spectrum of the dark areas, he tracked down indications of what may well be due to organic matter (23). It is too early to say that Sinton's work settles the matter once and for all, but it does make the theory of living organisms on Mars even more probable.

Assuming that we agree on the existence of "vegetation" of some kind or other, the next problem is to decide what it may be like. And here, unfortunately, we have to admit that we simply do not know. It is not probable that

advanced forms of plant life could survive under the rigorous conditions there, because there is not enough moisture, while the atmosphere is thin and oxygen-poor. We seem to be reduced to something of a much lower order, perhaps no more highly developed than our own lichens or mosses.

A lichen is a curious mixture of two quite different forms of life. One is a fungus, the other an alga; the two form a sort of partnership, and can flourish under conditions which most other life-forms would find extremely unpleasant (for instance, they can endure extreme cold). The spectra of the Martian dark areas somewhat resemble the spectra of Earth lichens, and in 1954 Hubertus Strughold, in a book treating the whole problem from the point of view of the biologist (24), suggested that the vegetation may be of this type. His basic idea was that the algæ produce oxygen in the normal way, and that this oxygen is trapped by the fungus and re-used, so that the whole organism would provide itself with what may be termed a "private atmosphere".

Yet we must be very wary of jumping to conclusions. As has been stressed earlier, Martian conditions are different from those of our own world, and it would be very dangerous to say that the "vegetation" there consists of lichens or anything else which we find on Earth. The only conclusion which appears to be reasonably safe is that in view of the hostile environment, Martian plants are not likely to be more highly developed than lichens or mosses. More will be said about this in Chapter Nine. Meanwhile, let us turn to alternative theories which have been put forward to explain the dark areas without involving living organisms at all.

Perhaps the best-known is that of the Swedish scientist Svante Arrhenius (25), advanced in 1912, and revived

much more recently by A. Dauvillier (26). Arrhenius supposed the dark regions to be overlaid with "hygroscopic salts", or salts which can absorb moisture. According to this theory, the surface salts pick up wetness from the melting polar caps, and darken, which does at least provide some explanation of the seasonal cycle. However, Kuiper (11) has pointed out that there is not enough moisture in Mars' atmosphere to make the process even remotely possible. Arrhenius' theory was put forward in the days when it was thought that Mars might have at least large-sized lakes, but there is nothing to be said for it now.

Different again is the volcanic hypothesis due to D. B. McLaughlin, of the University of Michigan (27). It was proposed in 1954, and is both interesting and revolutionary, though to my mind at least it has fatal weaknesses.

McLaughlin believes that the dark areas are nothing more nor less than volcanic ash, ejected from active volcanoes and distributed by the winds. After discussing the air circulation of Mars as compared with that of the Earth, with particular reference to the Martian equivalents of our trade winds, he goes on to suggest that the sharpish ends of features such as the Syrtis Major "point into the wind, and that they are essentially point sources of some dark material that is carried from these points, fanning out because of variable wind direction. If we restrict ourselves to natural phenomena of which we have experience on the Earth, the point sources can have but a single interpretation: they are volcanoes whose ash is carried by the winds and deposited in the pattern we see."

The irregular changes are attributed to outbursts of exceptional violence, and McLaughlin considers that the eruption which caused the alteration in form of the Solis Lacus, in 1926, was as great or greater than the disastrous

Krakatoa outbreak on the Earth in 1883. On the other hand, have we any evidence at all that active volcanoes exist on Mars?

Direct observations would naturally be difficult to obtain, as an eruption visible across a distance of at least 35,000,000 miles would be Titanic indeed. It is true that a bright spot observed on 8th December 1951 by the Japanese astronomer Tsuneo Saheki was widely reported as being due to a volcano, but this interpretation seems—to say the least of it—highly dubious, and it is much more likely that the phenomenon was caused by a high-altitude cloud catching the rays of the Sun. Indirect evidence is equally lacking. In its evolution, Mars seems to have progressed further than the Earth, and has probably advanced too far to be the scene of major eruptions now.

There are still some facts about terrestrial volcanoes which are imperfectly understood, but vulcanism seems to be bound up in some fashion with the distribution of water—all Earth volcanoes are comparatively near the sea—and there are certainly no oceans on Mars. Moreover, Öpik's argument must be borne in mind. Unless the ash is periodically renewed by constant eruptions from the "point sources", it will soon be overlaid by dust blown from the ochre tracts, and it is not easy to believe that the winds could be regular enough to preserve the ash deposits virtually unaltered in shape for hundreds of years. In addition, the volcanic theory seems quite unable to explain the seasonal cycle or "wave of darkening".

Finally, there is a proposal by three American astronomers—C. C. Kiess, S. Karrer and H. K. Kiess—that the Martian atmosphere contains poisonous oxides of nitrogen, which would mean a complete absence of life in any form (28). We will return to this idea later; for the

moment, suffice to say that although it certainly cannot be discounted, most authorities consider it rather improbable. And V. V. Sharonov, of the U.S.S.R., has advanced a theory according to which the processes of weathering and denudation on Mars, in the virtual absence of oxygen and water, give rise to large quantities of fine dust; dark regions would then be the areas of formation and deflation of this dust, while the bright regions would be the areas of its accumulation (29).

Yet when all is said and done, the picture of the dark areas as being due to living organisms remains not only the most attractive, but also the most plausible. Perhaps the space-probes of the near future, following in the track of Russia's *Mars I*, will give us positive proof. We cannot seriously believe, as Lowell did, that intelligent beings exist there, but it does seem as though the Red Planet, arid and unwelcoming though it may be, is at least capable of supporting living things of a type not totally alien to us.

CHAPTER FIVE

THE "DESERTS" OF MARS

THROUGH a powerful or even a moderate telescope, Mars is a beautiful object. The general hue is not scarlet, but warm ochre; the disk is marked by the darker patches, and there may well be a prominent white polar cap. Of all the planets, only Saturn is more striking.

Yet in reality it is this very ochre colour which tells us that Mars is so forbidding. It does not indicate warmth; the broad tracts are as unfriendly as they could possibly be. They are often termed "deserts", and the name is suitable enough, provided that we do not draw too close a comparison with the deserts of Earth.

It was some time before this was realized. The early observers were inclined to think that the prevailing red colour was due to some peculiarity of the Martian atmosphere, while during the period when the dark areas were believed to be seas the suggestion was made that the "continents" were covered with orange vegetation. However, when it was shown that there could be no oceans on Mars, the idea of "deserts" naturally followed.

To most people, the word "desert" conjures up a picture of a hot, sandy expanse, with oases here and there, together with occasional camels. This may be true of the Sahara, but it is certainly not true of the ochre areas on Mars. Oases may or may not exist—on the whole, they seem highly improbable—but not even the camel, that notoriously hardy creature, could survive under the

rigorous Martian conditions. Moreover, the deserts are not made up of sand. As has been pointed out by Tombaugh, sand is the accumulation of soiling and igneous rock débris by running water, and running water is absent from Mars. Even in past ages it is not likely that Martian conditions were suitable for the production of vast sandy deserts, covering five-eighths of the entire surface of the planet. Some other explanation must be found. We must remember, too, that the "deserts" of Mars are not hot. They seem, in fact, to be decidedly cooler than the dark regions.

On the maps of N. E. Green and other mid-nineteenth century observers, the ochre tracts were called "continents". Schiaparelli renamed them, but many of the boundaries between one tract and another are no more definite than, say, the frontier between Norway and Sweden, or between Canada and the United States. Thus the ochre region known as Æria merges into its neighbour Arabia. Here and there we meet "continental" regions which seem to be more definite in outline; one such area is Hellas, which often appears whitish, and is separated from the adjacent ochre tract of Noachis by a dark streak known as the Hellespontus, which seems to show considerable activity at times when the southern polar cap is shrinking quickly.

The general opinion of astronomers some sixty years ago was summed up by Lowell, when he wrote (30): "[The ochre tracts] seem to be nothing but ground, or, in other words, deserts. Their colour first points them out for such. The pale salmon hue, which best reproduces in drawings the general tint of their surface, is that which our own deserts wear. The Sahara has this look; still more it finds its counterpart in the far aspect of the Painted Desert of Northern Arizona." Subsequently it was

suggested that the surface rocks had combined with oxygen in the Martian atmosphere, with the consequent formation of a layer of iron oxide—in other words, common rust. This would account both for the predominating ruddy hue and for the present scarcity of free oxygen in Mars' atmosphere, as was pointed out by R. Wildt (31) in 1934.

Simple telescopic observations could shed little further light on the problem, but during the oppositions of 1922, 1924 and 1926 the whole matter was investigated by the French astronomer Bernard Lyot (32), who analyzed the quality of the light from Mars and compared it with moonlight. He also studied mixtures of grey, brownish and bluish volcanic ash. The results were of great interest. Lyot concluded that the Moon must be covered with a layer similar in nature to volcanic ash—and that it looked very much as though Mars had the same kind of coating.

We are still uncertain about the exact composition of the surface of the Moon, and we have no positive proof as to whether the large lunar craters are basically volcanic or not. Personally, I believe that they are (33); but in any case there can be little doubt that the Moon has been the scene of tremendous volcanic activity in the past. Yet it is not easy to believe that the deserts of Mars are due to volcanic ash, and Lyot was, justifiably, cautious.

Since then, the spectrum of the ochre tracts has been examined by various astronomers, and there seems every reason to suppose that the "deserts" are covered with a deposit of coloured minerals. The problem nowadays is to decide just what minerals are responsible, and so far there is no real agreement. G. P. Kuiper, in America, has compared the light of Mars with that of samples taken from deserts in the south-western part of the U.S.A., and has concluded that the bright areas are made up of igneous rocks similar to felsite (34); Dollfus, in France, has

carried out experiments along the same lines, but believes the coating to be due to limonite (35); V. V. Sharonov, in Russia, thinks that the ochre areas are covered with the silt of limonite particles (36). At any rate, we have come a long way from the hypothesis of sandy Saharas.*

If we are to gain a real understanding of Mars as a world, we must find out the nature of the surface—and this applies to the deserts as well as to the dark regions. Our present uncertainty was brought home to me in 1960, when I spent a fortnight in the U.S.S.R. I went to the "lunar and planetary laboratory" in Leningrad, where A. V. Markov and his colleagues are continuing the work of comparing the spectra of Mars and the Moon with the spectra of terrestrial samples; I also went to the Crimean Astrophysical Observatory and talked to N. Kozirev, who has revived the theory that the reddish hue of Mars is due not to the surface materials, but to the absorbing qualities of the planet's atmosphere. Even among experts, then, there is still a remarkably wide divergence of opinion.

In any case, it seems that the term "deserts" is by no means inappropriate. Five-eighths of all Mars is arid waste—chill, silent and hostile to all forms of life.

* For the benefit of those who are interested in chemical matters: felsite is a rock formed of orthoclase (aluminium and potassium silicate) with quartz grains in occlusion, while limonite is a sedimentary deposit of hydrated iron oxide, and has the chemical formula $Fe_2O_3 \cdot 3H_2O$.

CHAPTER SIX

THE MARTIAN ATMOSPHERE

THE MOST casual examination of a scale drawing of the Solar System is enough to show the division of the planets into two main groups. Basically, the four members of the inner group are similar. The Earth is inhabited; given breathable air, there would be every reason to expect intelligent life upon Mercury, Venus and Mars also.

"Given breathable air!" That is the crux of the whole question of advanced life on Mars. We know that the gravitation at the planet's surface is almost 4/10 of that of the Earth; that the temperature, though chill, is not intolerable; and that there is a little moisture. If the atmosphere proved to be reasonably dense and oxygen-rich, the Martians would at once step out of the story-books into the realm of probability.

As to the existence of an atmospheric mantle, there can be no doubt at all. As long ago as 1784, William Herschel wrote that "Mars is not without considerable atmosphere; for besides the permanent spots on its surface, I have often noticed occasional changes of partial bright belts; and also once a darkish one, in a pretty high latitude. And these alterations we can hardly ascribe to any other cause than the variable disposition of clouds and vapours floating in the atmosphere of the planet . . . [There is] a considerable but moderate atmosphere, so that its inhabitants probably enjoy a situation in many respects similar to our

own."* Schröter, the other great planetary observer of the time, went even further, and believed that the dark markings themselves were mainly atmospheric in nature, though it was not long before the patient work of Beer and Mädler showed that he was wrong.

Theoretically, of course, an atmosphere is only to be expected. On the other hand it is likely to be thinner than that of the Earth, because Mars has a lower escape velocity. This is precisely what we find.

Nowadays, the term "escape velocity" is familiar to most people, but it may be worth spending a few lines in explanation. Briefly, then, escape velocity is the speed at which a body would have to be projected from a planet in order to leave that planet permanently. If I could stand on the Earth's surface and throw a cricket-ball straight upward at 7 miles per second, it would never return; the pull of gravity would be unable to draw it back, whereas if projected with any lesser velocity the ball would fall to the ground.†

What we have to bear in mind is that the Earth's atmosphere is made up of particles moving at all sorts of speeds in all sorts of directions. A particle capable of working up to 7 miles per second would therefore have a chance of escape.

Our knowledge of the past history of the Earth is by no means complete, but it is generally thought that the present atmosphere is not the original one. In its early

* Herschel's views as to the habitability of other worlds were strangely sweeping. He firmly believed not only Mars but also the Moon to be inhabited; he even thought that intelligent beings might flourish in a cool region below the outer layers of the Sun. Rather unfairly, perhaps, some modern writers have ridiculed Schröter for holding similar though less extreme opinions, but have glossed over these queer views of Herschel's.

† Air resistance is neglected in this example, but makes no difference to the general principles involved.

stages, the Earth was presumably hot (though even on this point there is nothing like universal agreement); if so, the atmosphere must also have been hot, which would cause an increase in the velocity of the atmospheric particles. The original mantle escaped, and for a period the Earth was "airless". Then a secondary atmosphere was produced by gases expelled volcanically from beneath the crust, and the changed conditions meant that this secondary atmosphere was unable to leak away.

For Mars, the escape velocity is only just over 3 miles per second, and we must expect it to have lost a good deal of any atmosphere it may once have possessed. This is in fact the case. There are various methods of measuring the atmospheric pressure on the Martian surface, but so far the most reliable result seems to be due to Audouin Dollfus, who gives a value of 83 millibars—a mere $2\frac{1}{2}$ inches of mercury, as against an average of about 29 inches of mercury for the Earth (37). It is true that Russian astronomers give slightly higher values—112 millibars or $3\frac{1}{2}$ inches of mercury, according to N. N. Sytinskaya (38)—but it is clear that the pressure is far less than the pressure of our own air at the top of Everest. A terrestrial household barometer would be quite useless on Mars, unless drastically modified and recalibrated!*

We have found out a great deal about the Earth's atmosphere, particularly during the past few years, when it has become possible to make direct investigations by means of rocket vehicles. Generally speaking, we may divide the mantle into various layers. First there is the troposphere, extending upward to about 7 miles and which contains all normal clouds; above lie, in order, the stratosphere, the ionosphere, and the outer, incredibly

* Those pressure values are made on the assumption that the atmosphere of Mars is composed chiefly of nitrogen. See below.

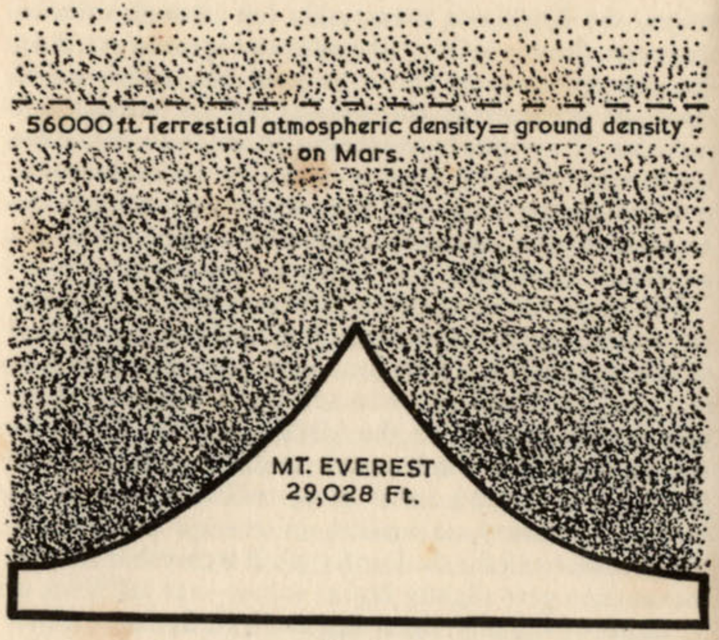
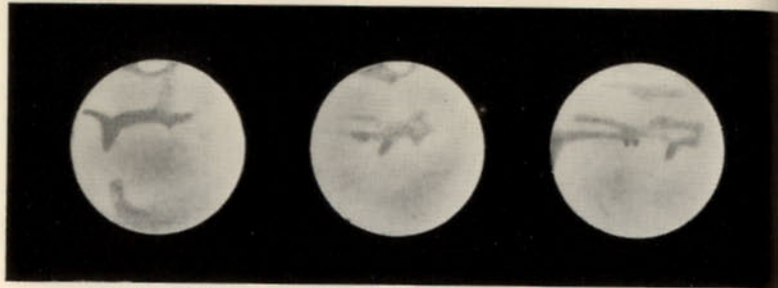


FIG. 10
Density of Martian atmosphere, compared with Everest

tenuous exosphere, which gradually "tails off" into space. It is impossible to say just where the atmosphere ends, since there is no sharp upper limit. The rockets have told us that the density of the upper air is much greater than was previously thought, and there may be traces of atmosphere left at distances of over a thousand miles above the ground, but the great majority of the atmospheric mass is concentrated in the troposphere—the bottom 7 miles. The density falls off very rapidly with increasing altitude, as every mountain climber and every airman knows.

Mars, photographed in the light of different colours. W. H. Wright, 1926

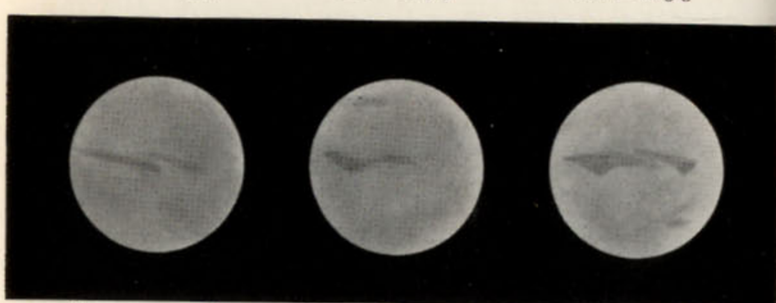
Mars, 1895. P. Lowell, Flagstaff Observatory.
Longitude 300° on the meridian



Aug. 25, 23 h.
12½″ Refl. × 260
CM = 063·7

Aug. 30, 23.25 h.
12½″ Refl. × 360
CM = 025·3

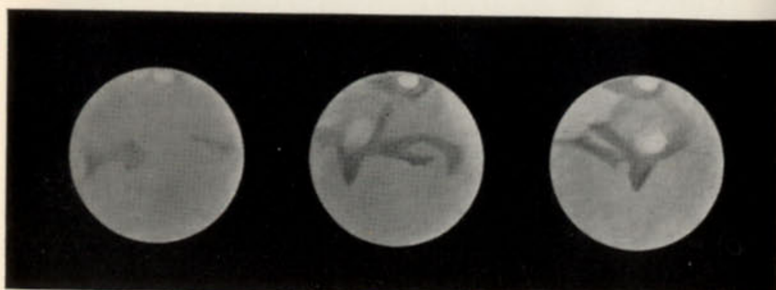
Sept. 2, 23.45 h.
12½″ Refl. × 360
CM = 003·5



Sept. 12, 20.50 h.
24″ Refl. × 460
CM = 232·7

Sept. 16, 20.33 h.
24″ Refl. × 400
CM = 193·2

Sept. 19, 22.45 h.
12½″ Refl. × 460
CM = 198·9



Sept. 29, 21.25 h.
12½″ Refl. × 360
CM = 092·9

Oct. 12, 21.10 h.
12½″ Refl. × 360
CM = 329·3

Oct. 18, 22.15 h.
12½″ Refl. × 360
CM = 290·1

The Obscuration of Mars in 1956

These drawings show the progress of the great 1956 "veiling" of Mars. All detail was hidden when the drawings of September 12 and 16 were made, but by mid-October the dark markings and the polar cap were again visible. Features may be identified with reference to the I.A.U. map; for each drawing the longitude of the central meridian of Mars is given

Drawings by Patrick Moore

The stratosphere contains a layer of ozone gas, a special form of oxygen, which (luckily for us) shields the Earth's surface from various harmful radiations coming from space; without such protection, no life on our world could have developed beyond a very primitive stage. In the ionosphere we find the layers which reflect radio waves back to the ground, and so make long-range wireless communication possible. We have no definite information as to whether Mars has layers of the same kind, but theoretical studies show that the density decrease with height is much less rapid than with the Earth. This leads to a rather peculiar result. At an altitude of 19 miles above the Earth, atmospheric density is the same as it is at 19 miles above Mars. Higher still, the Martian mantle will actually be the denser of the two. It follows that Mars has an atmosphere quite thick enough to protect the surface from meteoric bombardment.

A meteor is a small, solid particle moving round the Sun. When it happens to come close to the Earth, and enters the upper atmosphere, friction is set up against the air-particles, and the meteor becomes luminous as a "shooting-star". Since it is small, usually of lesser size than a grain of sand, and may be moving at anything up to 45 miles per second, it is destroyed before it reaches the ground; indeed, few meteors penetrate below 40 miles. They finish their journey in the form of fine "dust". The occasional large bodies which survive the full drop, and are then termed meteorites, are quite different from shooting-stars, and seem to be more closely related to the minor planets or asteroids.

At a relative altitude of 40 miles, the atmosphere of Mars is denser than that of the Earth. It will therefore provide a meteor-screen just as effective as our own. Of course it will not protect the surface from the far more

massive meteorites, but the Earth's mantle is equally inadequate. Future travellers to Mars need therefore have no fear of being subjected to a continual bombardment from space, whereas on the Moon, a world which is to all intents and purposes devoid of atmosphere, the meteor nuisance will have to be taken into account.

Next let us turn to the composition of the atmosphere. Here, of course, we have to depend upon the spectroscope. Mars shines by reflected sunlight, and basically its spectrum is simply a much enfeebled spectrum of the Sun; but we must remember that a ray of light reaching us from the planet has passed through the Martian atmosphere twice —once on its way from the Sun to Mars, and once on its way back from Mars to Earth. Both oxygen and water vapour, if present, would be expected to leave definite imprints upon the spectrum we see, and this applies also to other gases, though unfortunately ordinary nitrogen is very shy about revealing itself in the visible spectrum under such conditions.

The first measures were encouraging. In 1867 Jules Janssen, who founded the Observatory of Meudon (the square outside the entrance is still known as the Place Janssen) took his instruments up to the top of Mount Etna, 9,800 feet above sea-level, to study the spectrum of Mars without the handicap of having to look through the dense lower parts of our own atmosphere—which complicates matters because it contains its own oxygen and water vapour. Results seemed to indicate that the Martian mantle was fairly rich in water vapour, at least. This was also the opinion of Sir William Huggins, one of the pioneers of astronomical spectroscopy, and of the German worker Hermann Vogel.

The essence of Janssen's method was to compare the spectrum of Mars with that of the Moon. Both shine by reflected sunlight, but the Moon has no atmosphere capable of modifying the spectrum, so that any differences between the two would presumably be due to the atmosphere of Mars. Janssen's reasoning was perfectly sound, but his measures, apparently, were not, since the equipment which he had to use was very rough and ready judged by modern standards. Further researches failed to confirm his results, and it became clear that both oxygen and moisture were in very short supply.

In 1933 W. S. Adams and T. Dunham, at the Mount Wilson Observatory in America, made a close study of the whole problem, using equipment far more sensitive than Janssen's. They also employed a different line of attack. It is known that the positions of lines in a spectrum will be affected by the relative motion of the body sending out the light; this is the well-known Doppler Effect. If the light-emitting body is approaching, the spectral lines will be moved over towards the short-wave or "blue" end of the spectrum; if the body is receding, the shift will be to the red. When Mars is coming towards us, then, any lines due to (say) oxygen in the Martian atmosphere will be shifted towards the blue, whereas the lines due to oxygen in our own air will be unaffected. In this way it ought, theoretically, to be possible to disentangle the two sets of lines, and so work out how much oxygen there is around Mars.

The results obtained by Adams and Dunham were most interesting (39). They failed to detect any oxygen at all, and wrote that: "The final conclusion is that the amount of oxygen in the atmosphere of Mars is probably less than one-tenth of one per cent of that in the Earth's atmosphere over equal areas of surface". Eighteen years later, Cecilia Payne-Gaposchkin, of Harvard, stated that the upper limits for the Martian water-vapour and oxygen must be 5 per cent and 15 per cent respectively, compared with

the atmosphere of the Earth (40). The first gas positively indentified was carbon dioxide, by Kuiper in 1947 (41); according to these measures, the relative amount of carbon dioxide in the atmosphere of Mars was greater than for Earth, but strikingly less than for Venus.

It was only in 1963 that water vapour was definitely found. It was detected by A. Dollfus, at the Jungfraujoch in the Swiss Alps, and independently by H. Spinrad, G. Münch and L. D. Kaplan at Mount Wilson. The spectra showed unmistakable Martian water-vapour; the amount is of course very slight, as Spinrad has stressed (42), but at least the atmosphere of Mars is not completely dry.

The Earth's atmosphere is made up, by volume, of roughly 78 per cent nitrogen, 21 per cent oxygen, and 1 per cent other gases, mainly argon; carbon dioxide accounts for a mere 0·03 per cent. It may well be that the Martian mantle, too, consists chiefly of nitrogen, and in fact the percentage is likely to be very high indeed. According to de Vaucouleurs (43), the most probable composition is 98·5 per cent nitrogen, less than 0·1 per cent oxygen, just over 1 per cent argon, and 0·25 per cent carbon dioxide, presumably with traces of other constituents such as neon. That is as far as we are able to go. From the viewpoint of Earth-type animals and men, the atmosphere is totally unbreathable; indeed, it would be too thin for us to breathe even if it consisted of pure oxygen, a point to which we will return in Chapter Nine. As an aside, it is worth noting that there can be no fire on Mars, because of the scarcity of oxygen.

Before moving on to other problems, something more must be said about the theory by C. C. Kiess, S. Karrer and H. K. Kiess (28), who, as we have seen, paint a very unattractive picture of Mars. They maintain that the atmosphere contains poisonous oxides of nitrogen, and

that the polar caps are deposits of solid nitrogen tetroxide; the reddish colour of the planet is caused by the optical properties of nitrogen peroxide. The theory has been criticized by W. M. Sinton, who gives reasons for supposing that the unpleasant oxides could not exist in quantity (44), and on the whole is seems improbable, but it is not impossible. If it turns out to be valid, our hopes for establishing ourselves on Mars will be permanently dashed.

Although the spectroscope is still the most useful tool for investigating planetary atmospheres, there are still ways in which more direct methods may be used. One such method is to take photographs of Mars first in blue light, then in red. Blue* light, as we know, is made up of rays of comparatively short wavelength, and is easily scattered—which is why our skies appear blue; the rays of longer wavelength pass more easily through the air, which is why the Sun looks red when it is setting and is shining through a greater depth of atmosphere. (Astronauts such as Gagarin, Glenn, Titov and Nikolayev, travelling beyond the main atmosphere, have seen the sky as jet-black.) When photographs of Mars are taken in blue light they appear blurred, because the rays do not penetrate to the surface at all. They are stopped before they reach it, and all that we are photographing is the Martian atmosphere. Photographs taken in red light slice through the shielding layers and record surface details such as the dark areas and the polar caps with no difficulty at all.

Considering its comparative thinness, the Martian atmosphere is strangely obstructive to short-wave light.

* By "blue" is meant "light of comparatively short wavelength". Violet light, of course, is of shorter wavelength than blue; and photographs may be taken in ultra-violet.

Something acts as a screen, and this "something" is variable. There are times when it clears away, but it always comes back.

Obviously we are dealing with a definite layer (or layers) of material practically opaque to short-wave light. It has become known as the Violet Layer, not because it looks violet to the eye—visually it cannot be traced at all—but because it blocks the violet and blue light. Astronomers would very much like to know its nature, since it is quite obviously of the greatest importance in all Martian study.

All sorts of theories have been put forward. It used to be thought that the Layer must be caused by a haze of microscopic ice crystals floating in the planet's upper atmosphere, a view supported by authorities such as V. V. Sharonov in 1941 (45) and S. L. Hess in 1958 (46). This sounds plausible enough, but recent investigations by de Vaucouleurs (47) seem to have disposed of it. De Vaucouleurs studied Mars in the ultra-violet region of its spectrum. Ice crystals should reflect strongly in the ultra-violet, but Mars does not. Another idea, due to B. Rosen and revived in 1960 by E. J. Öpik, is that the Layer is caused by carbon particles (48, 49). The trouble about this is that nobody can see why carbon particles of the required size should form in the Martian atmosphere; there seems no reason for them to do so. It has even been suggested—by the Czech astronomer F. Link, in 1950 (50)—that the origin lies in meteoric dust swept up by Mars during its never-ending journey round the Sun. But the plain truth is that we simply do not know. Neither have we any positive information about the height of the Layer. It may well be placed between 8 and 10 miles above the surface of Mars, but estimates range from below 6 miles up to more than 60.

It seems, however, that the Violet Layer may be extremely useful to spacemen of the future, since it protects the Martian surface just as the ozone in our stratosphere protects the Earth (though it seems most unlikely that the Violet Layer consists of ozone). Sometimes, as we have noted, the Layer clears away, so that the planet is exposed to the full ultra-violet bombardment, and for a period photographs taken in short-wave light reveal the surface features almost as clearly as red-light pictures normally do. This happened, for instance, in May 1937, in October 1941, and again at the opposition of 1954. It may affect the whole planet, as in 1956, when the clearing lasted for more than a week; de Vaucouleurs recorded it from 25th August to 3rd September (51), and observers at the Lowell Observatory, Flagstaff, from 24th August to 2nd September (52). On the other hand, it may be confined to certain areas of the planet, as in 1958 (52); generally speaking, the greater the area affected, the greater the transparency.

The major clearings seem to give the *coup de grâce* to the idea that the Layer is made up of ice crystals, which occasionally sublime (i.e. turn directly from the solid to the gaseous state, so producing a temporary withdrawal of the screen). One would have to suppose that the temperature rose suddenly and uniformly over all Mars, which does not sound reasonable. But what about the effects on the dark regions? If these regions are made up of living organisms, damage ought to be caused when the Layer vanishes, and the seasonal cycle of development should be halted. This is precisely what was found by Hess during the clearing of 1941, which persisted for several days (53). During the time when the Layer was absent, Hess' photographic studies showed that the development cycle stopped, to recommence only when the Layer reformed

and conditions became normal once more. The observations not only confirmed the basic ideas about the Layer, but also provided an extra argument in favour of the theory that the dark areas are due to something which grows.

About a hundred and sixty years ago the French astronomer Honoré Flaugergues suggested (54) that since our atmosphere is subject to clouds, the Martian atmosphere might contain clouds of its own. In a way, Flaugergues was right, and clouds have been observed on many occasions; records of them go back to 1879 (55), and probably as far back as 1858, when Angelo Secchi, the great Italian pioneer of astonomical spectroscopy, saw something which seems to have been a white cloud. Yet there is no real analogy with our own storm-clouds, and rainfall must be completely unknown on Mars.

The clouds are of three main types: high-level ("blue"), intermediate-level ("white"), and low-level ("yellow"). There is still some difference of opinion as to whether the blue and white clouds are basically the same or not, but the three-type system has come into general use nowadays.

The blue clouds, revealed by short-wave light, seem to lie at a considerable altitude. They may be more than 50 miles above the Martian surface, though no reliable estimates are available; at any rate they are presumably composed of the same material as makes up the Violet Layer—whatever that may be. They were first recorded at the Pic du Midi Observatory, in 1909, by Baldet and De la Baume-Pluvinel. Dollfus regards them more as "hazes" than as true clouds.

More prominent are the white clouds, which are thought to lie at altitudes of between 4 and 16 miles. They can at times become really striking, and there are cases of unwary observers having thought that Mars had developed an extra polar cap or two! Examples may be seen

at most favourable oppositions. I have seen some prominent white clouds myself, even in 1952, when Mars was never very close. On 17th April of that year a brilliant cloud hid both Hellas and the Mare Hadriacum; it was still there on the 18th, after which clouds in our own air put a temporary but effective stop to my observations. Another striking cloud was seen on 17th May, covering the Nix Tanaica, close to the Mare Acidalium.

The popular theory is that the white clouds are composed of finely-divided ice crystals, so that fundamentally they are similar to the fleecy cirrus clouds which chase across our own skies and often foretell the approach of bad weather; but we cannot pretend to be at all certain. Then, too, there are numerous records of a whitish haze at the sunrise limb of the planet, attributed to some sort of condensation provoked by the fall of temperature during the night on Mars.

Most prominent of all are the yellow clouds, which really do look yellowish to the eye. Two famous examples were recorded in 1909 and 1911 by E. M. Antoniadi (56). The cloud of 23rd August 1909 blotted out the Trivium Charontis region and persisted for days; but the even greater obscuration of December 1911 covered vast areas of the southern hemisphere, from the pole down to as far as the Mare Tyrrhenum and the Deucalionis Regio. Some months passed before all traces of it disappeared.

Unlike the higher clouds, these yellow phenomena cannot be icy in nature. It is usually supposed that they are caused by dust blown up from the surface of the planet by winds. Winds in the Martian atmosphere are very mild by our standards, seldom reaching as much as 30 knots, and the best explanation may be that the clouds are produced by weather systems of the cyclone type. Inside such a system, the winds might attain greater

speeds, which would not, however, be detectable from the Earth in view of the fact that the weather system as a whole would move comparatively slowly across the Martian surface. Unless we return to that hoary old favourite, volcanic action, it is not easy to find a more plausible theory—and yet difficulties remain.

Note, for instance, what happened in 1956, when Mars was practically as close to us as it can ever come, and was expected to show a great amount of detail. Conditions were, to say the least of it, unusual. Many accounts have been published, and so I feel justified in giving my own observations, which do at least seem to tally with those carried out elsewhere. From England, Mars was inconveniently low in the sky, but with the 12½-inch reflector at my observatory I was able to see the usual surface features throughout August and the first part of September. Yet as early as 2nd September it was clear that something was amiss, and the polar cap, in particular, had become strangely obscure. I could still see the cap, plus the dark areas, on 8th September. At that point I decided that my reflector was not large enough to satisfy me, and so I took advantage of a kind invitation from the astronomers at the Observatory of Meudon, near Paris, to go and observe from there. The 33-inch refractor, used extensively by Antoniadi for Martian work (and with which I have myself carried out studies of the Moon) was out of action, since it was being remounted, but on 12th September I observed with the fine 24-inch Cassegrain reflector under good conditions. The disk was practically blank. I could make out parts of the Mare Cimmerium and the Mare Erythræum, but that was all; there was no trace of the polar cap. Similar views were obtained on other occasions during the following week. By 19th September the cap had reappeared, and after the 22nd it was as prominent as it

usually is at that stage of the seasonal cycle. The dark areas remained obscure, though visible, up to 12th October, after which conditions seemed to revert to normal.

For a time, then, Mars was hidden by a general "haze", and this haze covered the polar cap. Had it been caused by dust, the dust would have settled on the cap—and the cap itself would not have returned to its old whiteness nearly so quickly. I cannot explain the observations; I can only report them.

Now and then, unusual phenomena are seen which may or may not be due to clouds. One excellent instance is that of 8th December 1951, when a strange bright spot was seen over the Tithonius Lacus by Tsuneo Saheki, a very experienced Japanese observer. In Saheki's own words (57): "When I first looked at Mars some minutes before 21 hours 0 minutes, I saw Tithonius Lacus just inside the east limb. Very soon afterwards, a very small and extremely brilliant spot became visible at the east end of this marking. At first I could not believe my eyes, because the appearance was so completely unexpected . . . More careful examination revealed that it was not an illusion, but a true phenomenon on Mars." Subsequently it became brighter than the north polar cap, and then increased in size and faded, finally vanishing completely in less than an hour.

It was suggested that the flare was due to the eruption of a Martian volcano. Even less likely theories were put forward in the daily Press as soon as the report reached Europe; one famous London daily telephoned me to ask my views about "the atomic bomb that had gone off on Mars", and the landing of a giant meteorite was also referred to, while the Flying Saucer enthusiasts were predictably vocal. However, it seems that even the

volcano theory is highly dubious, and in all probability the spot was due to nothing more startling than a high-altitude cloud.

All things considered, the Martian atmosphere is just as complex and interesting as our own. Yet from one point of view, it is a disappointment. Whatever materials make up the Violet Layer, and whatever be the true nature of the clouds, we know that the Martian atmosphere can never support advanced forms of life built upon our own pattern. When we learn enough to reach Mars, we must either take our own air with us, or else manufacture it on the spot. We will never be able to breathe the chill, tenuous mantle which surrounds the Red World.

CHAPTER SEVEN

THE SURFACE CONDITIONS

IN 1907, a book entitled *Is Mars Habitable?* was published by the celebrated English scientist Alfred Russel Wallace. Percival Lowell had just written an account of his theory that Mars was a living world, and Wallace's book was a strong attack upon both Lowell and his ideas. It contained some sound science, but it also contained some statements which sound curious in the light of modern knowledge.

One such statement concerns the temperature of the Martian surface. In Wallace's own words (58): "All physicists are agreed that owing to the distance of Mars from the Sun, it would have a mean temperature of about —35° F. if it had an atmosphere as dense as ours. But the very low temperatures on the Earth at the equator, at a height where the barometer stands about three times as high as on Mars, prove that Mars cannot possibly have a temperature as high as the freezing point of water . . . [The temperature of Mars] is wholly incompatible with the existence of animal life."

In fact Wallace regarded Mars as an utterly frozen globe, icily chill even by comparison with the polar wastes of Earth. This view was supported three years later by Svante Arrhenius, of Sweden (59). As Arrhenius was a chemist outstanding enough to have won a Nobel Prize, his opinions could not be cast aside lightly. Yet we now know that although Mars is colder than Earth, it is much warmer than Wallace and Arrhenius supposed.

Measuring the tiny quantity of heat sent to us from Mars is a difficult matter, for obvious reasons. The only way to do so is to use a thermocouple together with a large telescope. A thermocouple is an instrument made up, basically, of two lengths of wire of different composition soldered together to form a complete circuit. When one join is heated and the other kept at a constant temperature, an electric current flows through the circuit; the current can be measured, and the amount of heat causing it may then be deduced. Of course, there are a great many refinements, but the main principle is straightforward enough.

In 1924, experiments along these lines were carried out by Pettit and Nicolson at the Mount Wilson Observatory, using a highly-sensitive thermocouple in conjunction with the largest telescope then in existence, the 100-inch Hooker reflector (60). At almost the same time, similar work was being done at Flagstaff by Menzel, Coblentz and Lampland (61), and the two teams agreed remarkably well.

At once it became clear that the conception of Mars as a frozen globe would have to be abandoned. According to the Mount Wilson readings, the temperature at the equator, at noon in midsummer, could rise to about +80 degrees F. As Coblentz pointed out from the Flagstaff work, the dark areas were decidedly warmer than the deserts; in the ochre tracts the temperature never rose much above 40 degrees. The poles were, naturally, much colder.

This seemed encouraging; Coblentz himself compared a Martian summer day with a bright cool day on Earth. Unfortunately the thin atmosphere is very inefficient at blanketing in heat, and so the nights are bitterly cold. Even at the equator, a thermometer would go down to at least −100 degrees F., and possibly even further; values

of −150 degrees F. have been suggested. And we are measuring the temperature of the actual surface; the atmosphere will be considerably colder.

On Earth, the record high temperature stands at +136 degrees F. (Tripoli, 1922) while the Russian meteorologists have stated that they have experienced about −100 degrees F. This means a total range of over 230 degrees F. Yet the same sort of range can be experienced on Mars at one and the same spot over a period of a single day, and it is easy to see why de Vaucouleurs has described the climate as being of "an exaggerated Continental type" (62).

The average temperature for the whole of Mars seems to be about −22 degrees F., well below freezing-point, and this has led to a suggestion by V. Davidov which sounds rather surprising. Davidov, scientific secretary to the State Astronomical Institute in Moscow, put forward his theory in 1960, and it was published in various Soviet journals. Broadly, it is a return to the old idea that Mars is covered with ice, though Davidov supposes that there is an extensive underground hydrosphere, i.e. a vast ocean below the Martian crust.

Davidov begins by pointing out that there can be no large seas on the surface of Mars. Any such seas would have been frozen over long ago, and covered by dust blown from the desert areas. He gives reasons for supposing that originally Mars had just as much water as the Earth, and that the interior of the globe must be at a high temperature. Davidov continues as follows:*

"At a depth of half a kilometre under the surface, a temperature must be reached at which the ice begins to melt. In the polar regions, where the average yearly temperature is so low, the thickness of the ice layer must be about 2 kilometres.

* For translation, I am indebted to J. Gerard Kilbride.

"As a result of earthquakes (or, rather, 'Marsquakes'), the ice, covered with the products of stone disintegration, would contain crevices which, despite the tremendous thickness of the ice, would probably break through. These crevices, in opening up, would permit water to contact the atmosphere, and a condensation of water vapour would result. This phenomenon will account for the mysterious white bands which are seen from time to time on Mars.

". . . The existence of a huge concealed water-envelope on Mars will account for the absence of mountain ranges on the planet. Let us imagine our own globe with its large oceans to be moving along in the orbit of Mars. The increased distance from the Sun would reduce the average yearly temperature; all our oceans would freeze, and would be covered with the dust of centuries and the products of stone disintegration. The absolute humidity would approach zero, and observations from another planet would give the impression that there was no water on the Earth. The Earth's surface would appear similar to that of Mars. . . .

"The planet has immense oceans, which are covered with a thick ice layer, and the great unevenness of the relief is almost completely camouflaged. However, it must not be taken that the Martian hills never towered up above the surface of the ice, as otherwise the ice would not be covered with the products of stone disintegration. The ice surfaces covered with such disintegration products will produce a dry polar desert of orange-red colour. Along positions of crevices lie oases, which when observed from a great distance blend together to appear as continuous lines, while the great masses of plant formations are seen as dark regions."

Ingenious though it may be, there are obvious weak

points in Davidov's theory, and it seems to have met with little or no support. However, it is true that Mars lacks major mountain ranges, and this brings us on to the whole question of Martian relief.

Mars is not a hilly world. In this it is utterly unlike Mercury or the Moon. We have no reliable information about Mercury, but the lunar peaks may well exceed 30,000 feet in height (33), outranking our own 29,000-foot Everest, and there are certainly no comparable mountains upon Mars. Intense erosion in the past is probably responsible. Erosion, the action of wind and water, is constantly wearing down the peaks of Earth, and has presumably done the same on Mars; but whereas ground activity lifts up new terrestrial ranges (the Himalayas are fairly recent by geological standards), Mars is comparatively inert. Erosion is naturally absent from the virtually "airless" Moon, and the lunar peaks stand out in their natural splendour.

It used to be thought that Mars must be flat and featureless, but this is probably much too extreme a view. One significant pointer is the uneven shrinkage of those all-important features, the polar caps. The icy or frosty covering in the far south persists upon the Novissima Thyle some time after neighbouring regions are clear, and this is taken to mean that the area is elevated; a similar explanation can account for the northern Olympia. Dollfus has calculated (63) that there may be plateaux at least 3,000 feet high in the polar zones. In more temperate latitudes there are certain isolated patches which may be even higher—the most prominent of them is the Nix Olympica—and the great desert tracts of Elysium and Hellas are often white while adjacent areas are not, which again may indicate higher altitude. And in 1956, Dollfus and his colleagues recorded a persistent cloud over

the Sinus Meridiani area which they attributed to "a hill or mountain hidden beneath the cloud" (64), while the same sort of phenomenon was seen over the Auroræ Sinus.

Dollfus has summed up the situation as follows (63): "Martian relief may be of the same order as that of the Earth, taking into consideration the relative diameters of the two bodies." This means that we may anticipate mountains up to something like 10,000 feet, though immense chains such as the terrestrial Rockies or the lunar Apennines are not likely to be found.

Unfortunately it is going to be an extremely difficult matter to observe the mountains directly. Such a thing is easy in the case of the Moon, because the phase ranges from new to full. They rays of the Sun will catch a mountain-top in preference to a valley below, and the terminator of the Moon, the boundary between the day and night hemispheres, always appears rough and uneven. Anyone who owns a pair of binoculars or opera-glasses can verify this for himself whenever the Moon is more than a day or two from full.

Mars never shows more than a slight phase, for obvious reasons; moreover it has only twice the diameter of the Moon, and is always at least 150 times as remote. In July 1952 Dollfus, at the Pic, did his best to detect irregularities along the Martian terminator which might indicate differences in ground level, but it is hardly surprising that he was unsuccessful.

One result of Mars' relative smoothness, coupled with the lack of sheets of open water, is that the winds are likely to be more regular than our own. So far the only definite information about them has been gained by watching the movements of clouds. For instance, Tsuneo Saheki detected a suitable cloud on 8th October 1952, which moved southward from the Mare Acidalium at an

average speed of some 10 knots, and was followed until 8th November (65). Ten knots is a very mild breeze by our standards, but, as we have seen, wind velocities on Mars are naturally less than in our own air. This is why it is likely that if the Martian yellow clouds are raised by winds, we must assume the existence of weather systems of the cyclone variety.

It has been suggested by P. Bernard (66) that the atmospheric conditions of Mars are linked with those of the Earth, since both depend upon events in the Sun, but the evidence is very rough and inconclusive. Then, too, Slipher, in 1954, put forward the idea that since clearings of the Violet Layer are seen only near oppositions of Mars, the Earth might have something to do with them, since at such times it lies more or less between Mars and the Sun (67). However, it now seems that clearings of the Layer are not confined to opposition periods (68). All things considered, our knowledge of Martian meteorology is still very slight, and unmanned rocket probes seem to hold out the best hopes for future research.

We have almost finished our brief survey of what Lowell once called the "natural" features of Mars. Let us sum up what we have found out:

Mars is a planet built upon much the same pattern as the Earth, its diameter being one-half and its mass one-tenth that of our globe. It is decidedly cooler, with a maximum equatorial temperature of slightly over 70 degrees F., and bitterly cold nights of at least −100 degrees F. The dark tracts on the planet are probably due to living organisms, while the ochre tracts are covered with coloured minerals. The polar caps are made up of an icy or frosty deposit; they shrink in the spring, and release moisture, which appears to affect the development of the dark areas in a regular seasonal cycle. The surface is

relatively level, and active volcanoes are unlikely. There is an appreciable atmosphere, which is however deficient in both oxygen and water vapour, and which could not support advanced life-forms built upon the terrestrial pattern. Clouds are of three types: hazes, white clouds probably made up of ice crystals, and yellow clouds attributed to "dust". The ground is normally protected from lethal short-wave radiation by the so-called Violet Layer, whose precise height and nature remain uncertain. When this Layer suffers temporary clearing, the "plants" suffer.

And so—to the Canals.

CHAPTER EIGHT

THE CANALS OF MARS

WHO HAS not heard of the Canals of Mars?

Whatever we may think about them, we are bound to admit that they are most peculiar objects. Half a century ago they were widely believed to be the visible results of engineering work carried out by the Martians, though modern scientific evidence is all the other way.

The story of the canals may be said to have begun in 1877, with a long series of observations made at Milan by the Italian astronomer G. V. Schiaparelli. The telescope used was only an 8¾-inch refractor, but the Italian skies are clear, and Schiaparelli himself was an expert in planetary drawing, so that he was able to produce charts which were better than any which had been previously made.

As well as recording the well-known features of the disk, Schiaparelli glimpsed other, more elusive objects which puzzled him considerably. The ochre areas appeared to be crossed by fine, dark lines which were so regular that they looked almost artificial. In Schiaparelli's own words (69):

"All the vast extent of the continents is furrowed upon every side by a network of numerous lines or fine stripes of a more or less pronounced dark colour . . . They traverse the planet for long distances in regular lines, that do not at all resemble the winding courses of our streams. Some of the shorter ones do not attain 300 miles; others extend for thousands . . . Some are easy to see; others

are extremely difficult, and resemble the finest thread of a spider's web drawn across the disk."

It is wrong to say that Schiaparelli discovered the canals; some of them may be traced on the drawings of Green, Dawes, and other observers of the mid-nineteenth century. Even Beer and Mädler had recorded a streak extending from the Lacus Phœnicis corresponding to the position of a canal later called the Dæmon. However, Schiaparelli was certainly the first to see them in large numbers (between 1877 and 1890 he recorded over a hundred), and he was also the first to pay serious attention to them.

Schiaparelli referred to the streaks as "canali", or, in English, channels. Unfortunately, perhaps, the Italian word was promptly translated as "canals", which implies artificial origin. I have never been able to find out who first suggested that the canals might be engineering works; the idea did not come from Schiaparelli, who however kept a completely open mind on the subject. In his own words: "Their singular aspect has led some to see in them the work of intelligent beings. I am very careful not to combat this supposition, which contains nothing impossible."

The most remarkable thing about the canal network was that it appeared to follow a definite pattern; there was nothing haphazard about it. Either the canals followed normal great-circle tracks across the planet, such as the Phison, or else they were gently curved, such as the shorter but broader Nilosyrtis. Whether curved or not, they ran from dark area to dark area; there was not a single instance of a canal ending abruptly in an ochre tract.

As well as observing large numbers of canals in 1877 and at the next opposition, that of 1879, Schiaparelli

found that some of them had a strange ability to become twins. Where there had previously been a single canal, two would appear. Sometimes one of the pair lay along the original track, sometimes the twins lay to either side of the old site. Invariably the two appeared strictly parallel, and equal in intensity. The doubling, or "gemination", was a rapid affair; a canal seen single one night might appear double the next. Neither were the separating distances the same for each set of twins. Some pairs might have a separation of as little as 50 miles, others as much as 400.

Throughout 1877 and the three following oppositions the canals remained unconfirmed; apparently no telescope except Schiaparelli's would show them, and astronomers in general were by no means convinced of their reality. Then, in 1886, Perrotin and Thollon, at Nice, using the 30-inch refractor at the Observatory, glimpsed the canal network and confirmed that the linear streaks really did exist in the positions indicated by Schiaparelli; they even drew eight double canals. They were followed by A. S. Williams in England, Terby in Belgium, and then by dozens of observers on both sides of the Atlantic. Canals became the fashion, and maps of Mars began to look very strange indeed.

Schiaparelli's failing eyesight forced him to give up active observing in 1890, but by then two other men had come very much to the fore—W. H. Pickering and Percival Lowell, both Americans. It was Pickering who first named the "oases", as he called the small dark patches where two or more canals intersected; Pickering, too, who detected canals on the dark areas, thus giving the death-blow to the old ocean theory. He also found that some of the oases were centres of radiating canals. For instance, at least six are said to issue from the prominent

dark patch known as Trivium Charontis, considered by Clyde Tombaugh to be deeply depressed below the level of the adjacent surface.

The central figure in all Martian study for the next thirty years was, however, Percival Lowell. Lowell was a man of many talents. He was a brilliant mathematician, writer and lecturer, and in his early days wrote several books dealing with a then-unfamiliar country, Japan. In the far future, when men of the nineteenth and twentieth centuries are discussed in much the same way that we of 1964 talk about Galileo and Isaac Newton, Lowell will probably be remembered chiefly as the mathematician whose work led to the tracking-down of a new planet, Pluto; but in the popular mind he will always be associated with the canals of Mars.

Lowell was quick to realize that the only way to study Mars in detail was to use a large telescope under really good conditions. Schiaparelli had had the clear skies, but not the aperture; his 8¾-inch refractor was a dwarf compared with giants such as the Meudon 33-inch and the Nice 30-inch. Lowell therefore founded his own observatory at Flagstaff in Arizona, equipping it first with an 18-inch and then with a 24-inch refractor. Many eminent men joined him there at various times—Pickering, Douglass and Slipher, to name only three—and in 1895 there began a steady stream of observations which has continued up to the present time. Lowell himself has been dead now for almost fifty years, but the observatory which he founded still lives on.

Lowell's first book on Mars (70), published towards the end of 1895, excited little comment. It was his second—*Mars and its Canals*, published in 1906—that was so explosive; indeed, it sparked off an argument seldom equalled in scientific annals.

Lowell was nothing if not whole-hearted. He stated, firmly and uncompromisingly, that there was only one way to account for the canals: they must be the work of intelligent beings who were striving to drain every scrap of water from the melting polar caps. What Schiaparelli had found was nothing more nor less than a gigantic, planet-wide irrigation system. Lowell summed up his views in the following words (71): "That Mars is inhabited by beings of some sort or other we may consider as certain as it is uncertain what those beings may be."

Lowell developed his ideas in a third book published two years later (72). He never believed that the canals were channels of open water. Folk as intelligent as he believed the Martians to be would certainly be too wise to risk losing most of their precious liquid by way of evaporation; it was much more likely that a typical canal was made up of a narrow strip of water, possibly piped, surrounded to either side by an area of cultivated land. Some enthusiasts, such as C. E. Housden, even went so far as to work out the form and power of the pumping stations required (73)!

The engineering problems involved would, of course, be tremendous. On the other hand Mars has no great mountain ranges, and the surface gravity is much less than that of the Earth. Moreover, it was necessary to assume that the Martians had reached a stage of real civilization, and that they had put all thoughts of war behind them, so that they could work together for the common good. In passing, it may be a useful reminder to quote Lowell's own words, taken from the last chapter of *Mars and its Canals*: "War is a survival among us from savage times and affects now chiefly the boyish and unthinking element of the nation. The wisest realize that there are better ways for practising heroism and other and more certain ends of

ensuring the survival of the fittest. It is something a people outgrow." This was written, remember, in 1906, but it still holds good today. It would be an excellent thing if every modern politician were made to learn those three sentences by heart.

It is perfectly fair to say that Lowell's theories about Mars would account for most of the observed phenomena. The canals would be expected to take part in the seasonal cycle, which, according to Lowell, they actually did; the geminations could also be explained, since if a single canal proved unable to cope with the available water supply a second channel, parallel to the first, could be opened at short notice.

On the other hand, there were several disturbing factors. Other observers, such as Hall (discoverer of Phobos and Deimos) and Hale (the pioneer mainly responsible for the building of the Mount Wilson and Palomar reflectors) were unable to see the canals at all; Barnard, a particularly good observer, was equally unsuccessful. Later a long study was made by E. M. Antoniadi, the Greek astronomer who lived for most of his career in France and observed with the Meudon 33-inch refractor. Antoniadi was just as emphatic as Lowell; he stated baldly that the canals did not exist. Probably Lowell was annoyed at the abuse and ridicule hurled at him, but not for one moment was his faith shaken. He continued his work at Flagstaff, and by the time of his death in 1916 he had mapped over 700 canals.

It is undeniable that the human eye does tend to join up roughly-aligned spots and streaks into hard, connected bands, and in 1903 an English astronomer, E. W. Maunder, tried to show that this was the true explanation of the Martian canals. He made some drawings of Mars, without canals, and showed them at a distance to a class of

boys from the Royal Greenwich Hospital School, telling them to make copies. When the boys did so, many of them showed sharp, linear canals, and Maunder concluded from this that the entire network was illusory (74). Lowell was not impressed. He dismissed the idea contemptuously as the "small boy theory".

For my own satisfaction, I repeated the experiment in 1950. The boys concerned were between 10 and 12 years old, rather younger than those in Maunder's class, but of a higher educational level, and more used to drawing. The pictures shown were actual drawings of Mars made through a large telescope, but with the canals removed and disconnected spots and streaks inserted instead. Out of a total of 58 boys, 42 showed vague indications of "something" where the canals should have been, 13 showed continuous broad, hazy strips, and only 3 showed Lowell-type canals. Of these three boys, two were notoriously inartistic and the third short-sighted. So far as they go, my experiments do not confirm Maunder's; but in any case, Lowell had much right on his side when he preferred to rely upon the work of trained observers using large telescopes rather than upon sketches made by a class of school-children.

The features have been seen so often, and by so many observers that they must have a basis of reality, but the first step is to decide exactly what is meant by a "canal". For example the Nepenthes-Thoth, running across the ochre tract near Syrtis Major, is obvious enough under good conditions, but it is not in the least artificial in aspect; it is broad, diffuse and only vaguely streak-like. And there seems to be no doubt at all that Lowell tended to draw the canals as much thinner and sharper than they really are. It is significant that he drew linear features not only upon Mars, but also upon Mercury, Venus and the satellites of

Jupiter. His drawings of Venus, showing regular markings which he likened to a "steel engraving", can only be described as fantastic (2). Moreover, he usually stopped his 24-inch telescope down to 18 inches or even less. There are two schools of thought here; some people maintain that a smaller aperture produces a sharper picture with more detail shown, others that the larger the aperture used, the better the view, provided that observing conditions are favourable. I hold the latter view. When using giant telescopes, such as the Meudon 33-inch and the 24-inch Lowell refractor itself, I have never had the slightest inclination to stop down the object-glass.

Photography, unfortunately, is of little help. The canals are elusive enough to be blotted out by the slightest tremor of the Earth's atmosphere, and this rules out time-exposures, whereas the human observer can take advantage of the rare moments of excellent seeing. The best Martian photographs so far taken show less detail than is visible with, say, the modest 12½-inch reflector in my own observatory. When dealing with the canals, the sensitive plate must yield to the eye.

Some astronomers still cover Mars with a Lowell-type canal network, but it is very difficult to eliminate personal prejudice, and it must—with the greatest reluctance—be said that the drawings of such a kind made with the help of small telescopes are of no scientific value. I have seen many such drawings, some of them made with 3-inch refractors, and the observers concerned have been honestly sure that they really did see the features. Yet even rough calculations are enough to show that the delicate lines shown would be far beyond the theoretical resolving power of the telescopes used, so that tricks of the eye are responsible.

On the other hand, it is only too easy to be prejudiced

in the opposite direction. I have made a good many observations of Mars between 1935 and the present time, using instruments of all sorts and sizes. I have never seen anything remotely like a "Lowell-type" canal; I can make out broader, somewhat streaky features, but that is all. I do not believe that the straight, narrow canals exist, and for that reason I would probably not see one even if it were staring me in the face!

During recent oppositions of Mars, Dollfus has been carrying out long series of observations with the 24-inch refractor at the Pic du Midi, in the French Pyrénées. The telescope is as large as Lowell's, and is said to be just as good optically; the Pic is 10,000 feet high, so that the atmosphere is as steady and as transparent as at Flagstaff. Broadly, Dollfus has divided the linear features into three distinct classes—wide, shady bands; narrow, more regular streaks; and true "canals", thread-like, perfectly black, and artificial-looking. The explanation given by Dollfus for the latter is (75) that they are purely physiological, produced by the mechanism of the human eye, while under conditions of perfect seeing the wider bands and streaks are seen to be broken down into separate dots and patches. Incidentally, Dollfus and J. Focas, also at the Pic, have been able to extend this "breaking-down" to the main dark areas (76, 77).

A slight digression here may be relevant. On the Moon there are some craters which show strange dusky bands extending from the centres to the walls. The most prominent of these banded craters is Aristarchus, which has a diameter of 23 miles and is much the brightest object on the whole Moon. The nature of the bands is not known, but they are certainly not due to any living organisms, as used to be thought possible. With ordinary apertures the bands seem continuous, but using the Meudon refractor in

1953 and the Lowell refractor in 1964 I was able to break them down into "fine structure" without much trouble (78).

Yet agreement is by no means complete. For instance, in 1956 R. S. Richardson, using the Mount Wilson 60-inch reflector, saw some canals as "bluish veins". This was on 3rd June; on 10th October he used the 100-inch reflector, and recorded that two canals were "distinctly seen as dark straggly streaks". The last word has by no means been said.

Most of the older observers believed the canals to be true water channels. Schiaparelli, for example, regarded them as "great furrows or depressions in the surface of the planet, destined for the passage of the liquid mass", and also stated that in his opinion "the canals are such in fact, and not only in name" (79). The main trouble about this idea is that we now know the polar caps to be very thin, and even if all the water in them could be released at the same moment it would fill only one or two large canals. Evaporation must also be taken into account. Even if we reject Davidov's theory, as most astronomers do, there is no reason to assume a lack of extra water supplies from below the crust; but in order to be visible to us, the canals must be so broad that the idea of their being open channels is decidedly far-fetched. The alternative suggestion of a piped channel surrounded by cultivated land is more reasonable if we are prepared to believe in intelligent Martians, but it is only logical to look for a purely natural explanation.

Pickering put forward a weird "aerial deposition" theory, according to which the canals were caused by vegetation springing up in the paths of storms that moved in straight lines across the Martian surface, shedding rain as they went. Nobody can doubt the value of Pickering's

contributions to astronomy, nor his skill as an observer, but some of his theories were unusual, to say the least of it —he was inclined to believe that there were insects on the Moon (80)—and his explanation of the Martian canals can hardly be taken seriously. Even worse was the suggestion that the canals are caused by meteors striking the surface of Mars and ploughing long furrows in it!

Clyde Tombaugh has put forward a much better theory, according to which the oases, the dark patches where canals meet, are craters formed in past ages by large meteorites or small asteroids striking Mars. The canals are regarded as cracks in which vegetation grows and spreads (81). However, we are again faced with the difficulty of the great breadth of the canals. Tombaugh's theory is similar to that proposed more than half a century ago by the Swede, Svante Arrhenius. Like Tombaugh, Arrhenius thought the canals to be cracks, but he replaced the vegetation by his favourite moisture-absorbing salts.

The only way to solve the mystery, unless space research comes to the rescue, is to continue observing the surface of Mars in order to find out just how the canals behave. They are always ready to spring surprises on us. Consider, for instance, the broad Nepenthes-Thoth, which, according to de Vaucouleurs (82) was faint and narrow, perhaps double, in 1939 and 1941, but which reappeared as a broad dark belt in the 1950s, becoming prominent again in 1958. And another canal, Erinnys, connecting the east and west tips of the Mare Sirenum to the Titanum Sinus, was seen in 1886 by Schiaparelli and again by G. Fournier in 1909 (83), but then vanished completely until recovered fifty years later by de Vaucouleurs (84). The real difficulty is that drawings of the positions of the canals made by different observers are often in sharp disagreement. This is understandable

enough when we are dealing with elusive objects at the limit of visibility, but it does not make for easy interpretation or correlation.

In short: Lowell's fascinating picture of a perfectly-organized planet, inhabited by thinking beings who are struggling desperately to survive upon a world which has already lost most of its water and is becoming more and more inhospitable as the æons roll by, has faded into the distance. The weight of modern science is opposed to it, even though we cannot yet claim that we know the full answer.

It is far more probable that the canals are composed of the same living organisms as make up the dark areas, whatever those may be. Few astronomers of today believe them to be artificial; but they are none the less interesting for that.

CHAPTER NINE

LIFE ON MARS

LONG BEFORE the term "science fiction" became part of our everyday language, and when the only interplanetary stories widely read were those of Jules Verne and H. G. Wells, Mars was considered to be the likely abode of intelligent beings. There were sound reasons for such a belief only seventy or eighty years ago. Until 1892 the dark areas were thought to be seas (for some reason or other, Liais' plant suggestion of 1878 did not attract much attention), and it was also believed that the Martian atmosphere was fairly rich in both oxygen and water vapour.

When it became clear that Mars was not a world capable of supporting advanced animal life built on the terrestial pattern, the idea of a civilization on the same lines as our own had to be rejected. If there were intelligent beings on Mars, they would have to be very different from ourselves.

In a novel, it is always possible to invent completely alien forms of life. H. G. Wells set the fashion in his *The War of the Worlds*, in which repulsive, all-conquering Martians descended upon the Earth and caused immense destruction before being destroyed by bacteria which did not occur upon their own planet. Wells has had many imitators, but it must be said that there is no evidence that what are known commonly as "bug-eyed monsters" can exist on Mars or anywhere else; all the scientific evidence

is to the contrary. Once we start discussing life-forms of a kind quite unknown to us, speculation becomes endless—and also rather pointless. So let us confine ourselves to life of the sort we can understand.

To begin with, it is quite definite that there are no Earth-type men on Mars. To stress this, something must be said about the process of breathing.

Oxygen is the essential gas; wartime fliers will remember the danger of going up too high without proper breathing masks. When oxygen is drawn in from the air, together with nitrogen—we can neglect the tiny amounts of other gases such as argon—it mixes with carbon dioxide and water vapour produced inside the body to make up a certain pressure in the lung. The human mechanism is adjusted so that the gas pressure inside the lung is always about the same, whatever the gas may be. If we breathe in less oxygen, more carbon dioxide and water vapour will be produced from inside the body to maintain the normal lung pressure. If we continue taking in less and less oxygen, there will come a point at which most of the mixture inside the lung is made up of irrespirable carbon dioxide and water vapour, so that unconsciousness and then death will follow. The critical point above which no outside oxygen at all can be taken in occurs at about 56,000 feet above the Earth, though, of course, the oxygen becomes insufficient for respiration well below this altitude.

It is probable that the atmospheric pressure at the surface of Mars is equal to that at about 55,000 feet above the Earth. Even if the Martian atmosphere consisted of pure oxygen, therefore, we would be unable to breathe it. But the mantle is not pure oxygen; it is practically pure nitrogen, and clearly it cannot be of the slightest use to us.

This argument applies also to Earth-type animals, and

it does not appear probable that any such creatures could survive under Martian conditions, even allowing for the fact that their lungs might be adapted to the environment. Of course, we cannot be sure. It is not absolutely out of the question that lowly animal life exists there, but the evidence, so far as it goes, is to the contrary.

When we turn to the plant kingdom, the situation is brighter—and as we have noted, it is almost certain that living organisms make up the dark areas, though we have no real clue as to what these organisms are. G. A. Tikhoff, of the U.S.S.R., supposes that they absorb the warming red and yellow light from the Sun and reflect the blue and green, which accounts for the characteristic hue of the dark regions (22, 85) and has built up what he regards as a whole new science of "astrobotany", but all we can really say is that the unsuitability of the atmosphere, together with the wide range of temperature, rules out advanced forms such as trees, bushes and flowers. The Martian organisms are not likely to be more developed than our lichens or mosses—though it would be highly premature to claim that they *are* lichens or mosses.

Something might be learned from attempts to find out whether lowly Earth organisms could adapt themselves to conditions on Mars. Various experiments have been conducted, and in 1960 I suggested to F. L. Jackson, of King's College Hospital, that it would be worth while to make some new investigations. Accordingly, special containers were built and filled with a "Martian atmosphere" (adopting de Vaucouleurs' figures for the composition) at the correct pressures. Various artificial "soils" were used, corresponding to those believed to exist on Mars; great attention was paid to the diurnal changes of temperature, and various ranges were tried, according to the best available measures of the actual temperatures on Mars.

The reduced gravity could not be simulated, but it was not thought likely that this would invalidate the experiments.

Work was begun in December 1960, and the first results given in the following March (86). Predictably, a single "Martian night" had a most depressing effect upon a cactus, which died immediately. (Nobody had expected anything else; but since various writers have suggested that the Martian deserts might support cacti, it seemed useful to demonstrate that not even the hardiest Earth-type cactus could survive!) The really serious experiments were carried out with micro-organisms, and microscopic plants, animals and bacteria were used. None of the plants or animals survived except for very limited periods, but the results with bacteria were more encouraging. Certain bacteria seemed definitely able to endure the conditions without marked adverse effects, and there seemed no reason to suppose that they would be unable to multiply. Limonite, which—as we have seen—may well cover much of Mars, discouraged some of the bacteria, but others tolerated it better. A second report, in 1962 (87) showed that only certain bacteria survived for more than a few days. Algæ, for instance, soon perished, though there may well be hardier species yet to be discovered.

The experiment is still going on, and only long-term work may be expected to produce really valuable results; it is, for instance, important to find out whether any Earth organisms can reproduce under Martian conditions, and, if so, whether an evolutionary process takes place.

Finally, it has often been suggested that Mars was once the abode of higher life (intelligent or animal), and that this life died out when the planet lost a large proportion of its water and oxygen. Here, unfortunately, we have no

positive information, and we cannot hope to find out definitely until the first space-probes tell us whether or not the Martian crust contains fossils.

One point of view may be put forward, though it may be of no real significance. The age of the Earth is between 4,000 and 5,000 million years, but life did not appear until perhaps 2,000 million years ago. In other words, the Earth was lifeless for about one-half of its career to date. There are excellent reasons for believing that Mars and the Earth were born at about the same time, and that Mars, smaller and less massive, lost its water and much of its atmosphere more quickly. Therefore, would life have had time to evolve there before the planet became hopelessly hostile? On the face of it the answer would seem to be "no", but it may, of course, be that the whole process of evolution was speeded-up, and that life appeared on Mars before developing on Earth. I admit to serious doubts as to whether future explorers will find fossils in the Martian crust, but I am quite ready to be proved wrong.

To sum up: there is no reason to doubt that lowly organisms survive on Mars, and there is a great deal of evidence that they do. On the other hand, the thin, oxygen-poor atmosphere is certainly unable to support either men or higher animals. The fascinating Martian forests, with their gay red flowers and towering trees, do not exist outside the story-books, and the brilliant engineers of the Red Planet are no more real than the shadowy gods of Ancient Olympus.

CHAPTER TEN

THE SATELLITES OF MARS

THE YEAR 1877 was important in the history of Martian study. It saw the discovery of the full canal network, by Schiaparelli; it also saw the discovery of the two tiny satellites, Phobos and Deimos.

It had long been known that the Earth is not the only planet to have a moon. Among the first objects to be discovered by Galileo in 1609, when he first turned a telescope towards the sky, were four starlike objects which were close to Jupiter, and soon proved to be true Jovian satellites. Almost fifty years later Christiaan Huygens discovered a satellite of the second giant planet, Saturn, and with increasing telescopic power more and more such bodies came to light. By 1850 the total number of known satellites was seventeen—four revolving round Jupiter, eight round Saturn, four round Uranus and one round Neptune.

However, the three inner planets, Mercury, Venus and Mars, appeared to be without attendants. A satellite of Venus was reported now and then, but was clearly nothing more than a telescopic "ghost", while in 1783 William Herschel had made an unsuccessful search for a Martian satellite. Heinrich d'Arrest, sometime Director of the Observatory of Copenhagen, returned to the attack in 1862, but once again the result was negative, and the general feeling among astronomers was that Tennyson

had been right in singing of "the snowy poles of moonless Mars".

In 1877, when Mars was extremely well-placed for observation, Asaph Hall, an American astronomer of wide fame, decided to have one more attempt to find the elusive satellite. He was well-equipped for such a search, since he had at his disposal one of the largest refractors in the world, the Washington 26-inch. On 10th August 1877 he started work in earnest. For some time he saw nothing except the usual background of stars, but at 2.30 in the morning of 11th August he caught sight of a faint object very close to Mars which seemed to be much more promising.

Unfortunately, fog rising from the nearby Potomac River came up before he had time to do more than secure a quick observation of the suspected object, and clouds and mist prevented anything further being done for the next four nights. On 16th August, however, all was well again. The object was seen once more, and was clearly moving along in company with Mars, so that it seemed to be a genuine satellite and not merely a star. On the following night there were startling developments. The original satellite was recovered, and another detected, closer to Mars than the first.

Hall's announcement, made on 18th August, caused a great deal of excitement, which increased when it became obvious that the inner satellite, at least, was a most peculiar object. In Hall's own words (88): "At first I thought that there were two or three moons, since it seemed to me at that time very improbable that a satellite should revolve around its primary in less time than that in which the primary rotates. To decide this point, I watched the moon throughout the nights of 20th and 21st August, and saw that there was in fact but one

inner moon, which made its revolution around the primary in less than one-third the time of the primary's rotation, a case unique in the Solar System."

This was indeed remarkable. Mars' axial rotation is much the same as that of the Earth ($24\frac{1}{2}$ hours), but the inner satellite proved to take only 7 hours 39 minutes to complete one revolution. For it, therefore, the "month" was shorter than the "day"!

The names selected for the two moons were happily chosen. The outer and first-discovered was named Deimos (Terror or Flight), and the inner Phobos (Dread or Fear), after the two attendants of the Olympian War-God; Homer, in the fifteenth book of the *Iliad*, written perhaps three thousand years earlier, had written:

> He spake, and summoned Fear and Flight to yoke
> His steeds, and put his glorious armour on.

It was not difficult to see why the satellites had not been discovered before. They are among the smallest celestial objects known to us (excluding meteors, of course), and seem hardly fit to be ranked as true satellites at all. Deimos is perhaps 6 miles in diameter, Phobos not more than 12. These values are not precise, but they are certainly of the right order. Moreover, even when Mars is at its closest to the Earth, the satellites will be only 20 seconds and 65 seconds from the planet's limb at their greatest elongations. Fairly large instruments are needed to show them at all. I have just caught one with my $12\frac{1}{2}$-inch reflector, but it was at the very limit of visibility, and I have never managed to repeat the observation. With a $15\frac{1}{2}$-inch reflector it is possible to see both, but not easily. When H. P. Wilkins observed Mars in 1954 with the 60-inch reflector at Mount Wilson, he recorded that Deimos, which was well-placed at the time, appeared only as a

tiny point. Needless to say, any study of their surface details is absolutely out of the question. E. M. Antoniadi stated (89) that Phobos was generally white, Deimos bluish; but no other colour estimates have been published, and it must be said that the colours reported by Antoniadi are of dubious reliability, particularly as they were made with a refracting telescope.

We cannot even be sure that Phobos and Deimos are spherical. They may well be irregular in shape, and may possibly fit the description of "lumps of rock"—though we are similarly ignorant as to their composition. Neither can retain any vestige of atmosphere. Their escape velocities are low; about 30 m.p.h. for Phobos, about 15 m.p.h. for Deimos. Yet is is not true to say, as some writers have done, that a man standing upon one of them and leaping skyward would move off into space and never come back; actually, an average man would be unable to jump clear of any globe with a diameter greater than 2 miles, assuming a density equal to that of the Earth. (He would, of course, "fall" extremely slowly back to either Phobos or Deimos.)

There is a curious story attached to the dwarf satellites. In 1727, a century and a half before Hall's discovery, Dean Swift, in his classic *Gulliver's Travels*, had written that the astronomers of the mythical flying island of Laputa had discovered "two lesser stars, or satellites, which revolve about Mars, whereof the innermost is distant from the centre of the primary planet exactly three of his diameters, the outermost five; the former revolves in the space of ten hours, the latter in twenty-one and a half" (90). At the time of Swift's death, in 1745, no telescope in existence was of sufficient power to show either satellite, and his description must therefore have been nothing more than a "shot in the dark", but it was none the less quite remarkable.

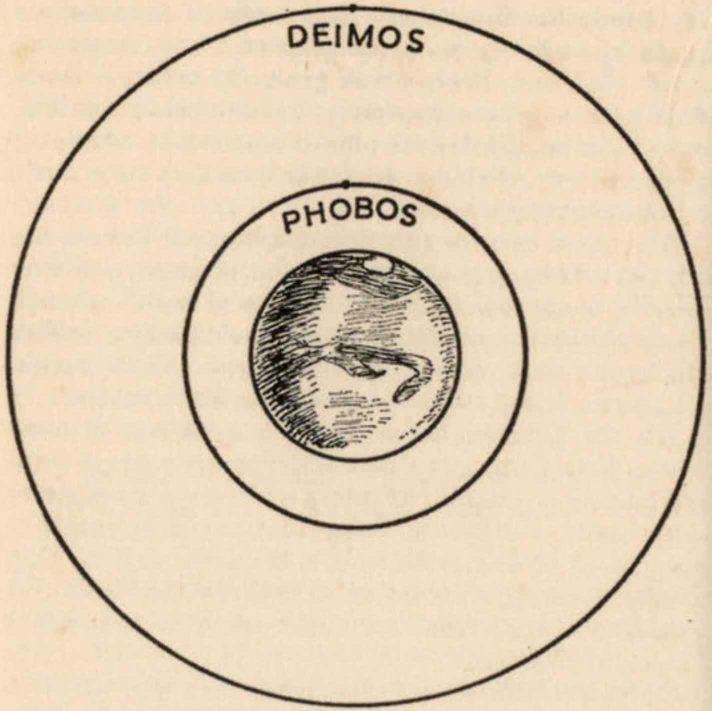


FIG. 11
Orbits of Phobos and Deimos (to scale)

The story was repeated in 1750 by Voltaire in his strange tale *Micromégas*. He reasoned that since Mars is considerably further from the Sun than we are, it could hardly manage with less than two moons.

Phobos is perhaps the more peculiar of the satellites. Its distance from the centre of Mars is a mere 5,800 miles. This means that its height above the planet's surface is no more than 3,700 miles, or roughly the distance from London to Aden. An observer standing at a high latitude

on Mars would never be able to see it at all, since it would be permanently invisible from latitudes greater than 69 degrees north or south. To an observer at the Martian equator, however, it would appear as a disk about one-third the size of the Moon as seen from the Earth.* Its quick revolution would result in some curious phenomena. Like some of the artificial Earth satellites launched since 1957, it would appear to rise in the west and set in the east. It would take $4\frac{1}{4}$ hours to cross the sky, during which period it would go through more than half its cycle of phases from new to full, while the interval between successive risings would be 11 hours 6 minutes. Moreover, it would seem appreciably larger when high up than when low down. Often, of course, it would be eclipsed by the shadow of Mars, and only near midsummer and midwinter would it be free of shadow for the whole of its passage across the sky. As a source of illumination at night, it would be of little use.

Deimos, moving at a distance of some 12,500 miles above the surface of Mars—roughly the distance between England and Australia—has a revolution period of rather more than 30 hours; like Phobos, it has an orbit which is almost circular, and practically in the plane of the Martian equator. As Mars spins, Deimos almost keeps pace with it, and remains above the horizon at any one place for more than 60 hours at a time, during which period it passes through its complete cycle of phases twice; it too is invisible from the polar regions, the limiting latitude being 82 degrees north or south. Its eclipses would be similar to those of Phobos, though not quite so frequent. To a Martian observer, Deimos would hardly show a

* This figure, too, is far from precise, because we do not know the diameter of Phobos accurately. It might well have an apparent diameter, as seen from Mars, of only one-fifth that of the Moon as seen from Earth.

perceptible disk, and would appear much more like Venus as seen from the Earth, though rather larger and considerably dimmer.

The two moonlets undergo all sorts of eclipses and occultation phenomena. They pass in and out of the shadow of Mars, and to a Martian observer they would also appear to pass in front of the Sun's disk. When our own Moon passes between the Earth and the Sun, it is capable of blotting out the bright solar surface, so that the Sun's outer atmosphere flashes into view; nobody who has seen a total solar eclipse is likely to forget it. Seen from Mars, however, neither Phobos nor Deimos can cover the Sun completely. Phobos hides 1/3 of the Sun, and passes across the disk in about 19 seconds; this happens about 1,300 times in each Martian year. Deimos passes in front of the Sun 120 times a year, but covers only 1/9 of the disk, and takes 2 minutes to move right across. This means that Martian astronomers—if they existed—could never see the Sun's surroundings, such as the corona and prominences, with the unaided eye.

One rôle of our Moon is to influence the oceans, producing the tides which are so important in shipping. There are no large sheets of water on Mars now, but in any case neither Phobos nor Deimos would be capable of producing an appreciable tide. The Martian seas would be still and sluggish by our standards, particularly in view of the lightness of the winds and the less powerful tidal effects of the Sun.

It has been suggested that in the future, when space-travel to Mars has been achieved, Phobos and Deimos will be utilized as refuelling bases. The difficulties are very great, and to discuss them in detail would be premature, but recently there has been another suggestion which is as curious as it is unexpected. It comes from the Russian

astronomer I. Shklovsky (96), who believes that the satellites are nothing more nor less than artificial space-stations, built by the Martians for reasons of their own!

Calculations made in 1945 by B. P. Sharpless (91) and in 1954 by F. J. Kerr and F. L. Whipple (92) have indicated that Phobos is gradually approaching Mars, and is speeding up in its orbit, while Deimos is probably receding. If so, Phobos might well strike Mars, and come to the end of its career, in from 35,000,000 to 40,000,000 years from now (93). It is still outside the Roche limit, but not by very much. Whether it would be broken up as soon as it passed within the Roche limit would depend upon its composition; if it were solid and rocky, it would not.

Even if the calculations are valid, the approach of Phobos to Mars is very slow indeed. Shklovsky, however, believes that the slight speeding-up is due to the fact that Phobos is moving through the outer, very rarefied part of the Martian atmosphere. Were it a normal body it would be unaffected, but a body of very slight mass would be more greatly influenced by the resistance of even a tenuous atmosphere. According to Shklovsky's reasoning, the fact that Phobos is so affected shows that its mass is negligible. It cannot have a diameter of much less than 10 to 12 miles, as judged from its apparent brilliancy, and so it must be hollow. Shklovsky goes on to infer that it must be of artificial construction, while the same would apply to Deimos. The failure of Herschel and d'Arrest to see them before 1877 is accounted for by supposing that the satellites did not then exist, as they had not been launched . . .

Let it be said, at once, that Shklovsky is an outstanding astrophysicist who has been responsible for some most important advances in our understanding of the stars. Yet

his theory about Phobos and Deimos is hard to discuss seriously. Even if Phobos really is approaching Mars, there seems no reason to introduce an hypothesis which is so utterly opposed to all scientific evidence, and to deal with it further would be somewhat pointless. Much though I would like to believe in intelligent Martians, I fear that space-travellers of the future will find Phobos and Deimos to be natural bodies rather than metal shells.

The problem has been re-examined of late by G. F. Schilling (97), who considers that certain assumptions about the Martian atmosphere might lead to a marked effect even on a Phobos made of solid rock, and by E. J. Öpik (98), who does not reject Shklovsky's theory out of hand—as I do!—but suggests that the curious behaviour may be due "to the inelastic response of the solid mantle of Mars to the gravitational pull of Phobos".

There is little similarity between our Moon and the two dwarf attendants of Mars, and it may well be that Phobos and Deimos are simply asteroids which were captured in the remote past. They have already been useful to astronomers, since studies of their movements have yielded improved values for the mass and figure of Mars itself, but they remain something of a puzzle, and will continue to do so until we can examine them from close range instead of seeing them as no more than tiny points of light in our largest telescopes.

CHAPTER ELEVEN

ROCKETS TO MARS

On 1st November 1962, Russian scientists launched a space-probe towards Mars. The first part of the experiment, at least, was successful; the vehicle, *Mars I*, was launched into a correct orbit, and for some time all went well. Then, unfortunately, faults developed inside the probe itself, and radio contact with it was lost, never to be regained. When last contacted, it was more than 60,000,000 miles from the Earth.

There had been several previous planetary probes, notably the U.S. vehicle *Mariner II*, which by-passed Venus at a mere 21,000 miles in December 1962, and which provided information which was, to say the least of it, unexpected. At the time when these words are being written (January 1965) two further probes to Mars are on their way.

The story of rocket research has been told often enough, and I do not propose to repeat it here. Suffice to say that the fundamental principles were laid down in the early part of the present century; that the first "modern-type" rocket, using liquid propellants, was fired by R. H. Goddard in 1926; that the Germans, led by men such as Wernher von Braun, developed long-range, high-altitude rockets during the War, so opening the way for the direct exploration of space; and that the first artificial Earth satellite was launched by the Russians in 1957. Two years later the Soviet team managed to send three rockets

towards the Moon, one of which (Lunik III) went on a "round trip" and sent back photographs of those parts of the lunar surface which are always turned away from us, and which can never be seen from Earth. The next step, obviously, was to send probes towards the planets. Venus was first on the list. The original vehicle, again of Russian construction, was launched in 1961, and may have passed within 65,000 miles of Venus, but radio contact with it was lost at an early stage, and we will never know what happened to it. The difficulties of maintaining radio links are indeed great, and this stresses the magnitude of the American triumph with *Mariner II.*

Mars, at its nearest, may come within 35,000,000 miles of the Earth, but unfortunately it is not possible to wait for the most favourable moment and then simply fire a rocket vehicle directly from the one world to the other. This would mean using power for the whole journey, and no rocket depending upon modern-type chemical propellants could possibly carry enough fuel. Basically, what has to be done is to launch the probe by rocket power, and accelerate it relative to the Earth, so that it swings outward from the Sun in a "transfer orbit". It can then carry out almost all its journey in free fall, without any further application of power, the idea being to take it to the orbit of Mars and make it arrive at a predetermined point at the same time that Mars itself does so. Everything has to be very accurate. A velocity error of one foot per second, or a directional error of one minute of arc, will make the probe miss Mars by over 12,000 miles.

According to the official Soviet reports, *Mars I* consisted of two airtight compartments. The first contained apparatus ensuring the operation of the probe during the flight—in particular, certain corrections to its orbit had to be made, as was the case with *Mariner II*, and there were also

solar batteries, devices to control the temperature inside the vehicle, and radio antennæ. The second compartment held the scientific instruments which were intended to come into action when Mars drew near. The total length of the vehicle was 130 inches, and its weight 1,970 pounds. During the launch, the probe itself was covered by a protective cone, which was discarded once the Earth's atmosphere had been left behind. The solar batteries, antennæ and other pieces of delicate apparatus were folded up underneath the protective cone, and after the probe itself had been separated from the final stage of the launcher these pieces of equipment were unfolded to take up their prearranged positions.

Even during the first part of its journey, *Mars I* proved its worth. It sent back new data about matters such as the radiation belts surrounding the Earth, the frequency of meteoritic particles, and cosmic rays—those strange high-speed particles whose origin is still largely unknown. It also measured some of the magnetic fields encountered in space, and whose significance is becoming more and more evident as time goes by. Signals showed that the atmospheric pressure inside the probe was steady at about 850 mm. of mercury, with a temperature of from 20 to 30 degrees Centigrade; there was no difficulty in communication, and there was every reason to suppose that modifications could be made to the orbit, as the Americans had done with *Mariner II.*

The main work was, however, to be done when the rocket and Mars were relatively close. It was hoped, for instance, to measure the Martian magnetic field (assuming that one exists), to obtain spectra showing once and for all whether the dark areas contain organic matter, to analyze the planet's atmosphere, and even to send back television pictures of Mars from close range.

It was a great pity that contact with the probe was lost in mid-flight, but at least the experiment was not discouraging. It remains to be seen when the first successful vehicles will be launched. More ambitious still is to land a vehicle on the Martian surface, gently enough to avoid destroying the instrumentation. If this could be done, samples of the planet's crust might be analyzed, and the results sent back by television techniques. A programme of this kind is now under way with regard to the Moon, and if it succeeds there is no reason to doubt that the same principles will be used in Mars probes.

There were further developments in November 1964, when three Mars-shots were tried. *Mariner III*, launched on November 5, was a total failure, but *Mariner IV* of November 28 achieved orbit successfully, and at the end of December was still behaving excellently. On November 30 the Russians dispatched *Zond II*, also without mishap, though the behaviour of the probe's transmitters gave cause for alarm. Both vehicles should approach Mars in mid-1965.

Manned interplanetary flight lies further in the future. The Moon is almost within our reach, but the lunar trip is a parochial hop, and the journey to Mars will be vastly more difficult. The outward and the return voyages will each occupy months—unless, of course, we learn how to master nuclear fuels—and there will be a prolonged stay on the planet itself, or in orbit round it, before the homeward flight can be begun. In fact, the explorers will be away for over two years, and this raises a host of so-called "minor" problems which actually prove to be anything but minor.

Until we have more information, we cannot tell how far Mars will help the pioneers when they arrive. The chief trouble, of course, is that the atmosphere is unbreathable,

and it does not seem probable that edible terrestrial-type plants will be able to gain a foothold there. Much hinges upon whether there are underground water supplies. If there are, things will be considerably easier than would otherwise be the case.

The question of a permanent or semi-permanent base on Mars must also be considered. The popular idea of such a base is attractive enough—a collection of airtight domes, kept inflated by the pressure of atmosphere inside them, and which are entered by means of special airlocks; but whether anything of the sort will prove practicable remains to be seen.

Mars is much more remote than the Moon, but it is also a much more inviting world, and it seems that the only factor likely to stop our reaching it eventually is the outbreak of a third world war—which would, of course, put an end not only to space exploration, but also to humanity. Meanwhile, we can only hope for the best. We of the mid-twentieth century have been born too early to explore the deserts and the frosty caps of Mars, and must be content to gaze at them through our telescopes; but at least we can try to ensure that our children and our children's children are given the opportunity to travel through space.

APPENDIX I

OBSERVING MARS

MARS IS a difficult telescopic object—and this fact is often not realized by the beginner, who buys a small telescope, pokes it through a window, and expects to see a network of canals! Moreover, the planet is well seen only for a few weeks every alternate year, and advantage should be taken of every clear night during these periods. There is little to be seen, even with moderate telescopes, when the angular diameter of the disk is less than 6 or 7 seconds of arc.

Martian work involves the use of rather high powers, and this means that a small telescope is of limited value. In general, the minimum aperture is about 8 inches for a reflector and 6 inches for a refractor, though the broad details, such as the main dark areas and the polar caps, can of course be seen with apertures as small as 3 inches.

Much depends upon the altitude of the planet. It is of no use trying to study Mars when it is low in the sky, and it must also be added that drawings made with very small telescopes, such as 3-inch refractors, must be rejected as totally unreliable if they show fine details such as canals. This is no reflection upon the integrity of observers who have produced such drawings; but the human eye is notoriously easy to deceive, and there is always the tendency to draw in what one half-expects to see.

It is advisable to adopt a set scale for drawings. The workers of the B.A.A. Mars Section favour 2 inches to the

planet's diameter. The phase must never be neglected, except close to the time of opposition, when the disk appears virtually circular; but phase effects are easily allowed for, as the appropriate phase may be looked up in some publication such as the *B.A.A. Handbook*, and a disk outline prepared before the actual observation is begun. The axial pose may also be calculated. A useful paper on this subject was published by M. B. B. Heath some years ago (94).

The first step is to survey the planet and form an idea of what is on view. Then sketch in the obvious details, such as the polar cap and the main dark regions. When this has been done, check carefully and note the time (using the 24-hour clock, and ignoring Summer Time). These main features should then be left unaltered. There is a good reason for this; Mars is rotating all the time, and the drift of the markings across the disk is perceptible even over periods of a few minutes.

Now change to a higher magnification and fill in the minor details, paying particular attention to the relative intensities of the various features and to such interesting phenomena as the fringes of the polar caps. Note, too, which markings lie on the planet's central meridian, as these are useful for longitude-checking. It is also important to orientate the drawing—not by estimation from the polar caps, which are not always exactly at the true poles, but by allowing Mars to drift through the telescopic field and noting the "preceding" and "following" points.

Written notes, dealing with features of special interest, can be added at leisure, and the whole drawing checked for accuracy. Finally, the following data should be added: date, time, name of observer, type and aperture of telescope, magnification, seeing and transparency conditions, and the longitude of the central meridian at the time of

observation (calculated from tables such as those in the *B.A.A. Handbook*; it involves nothing more abstruse than simple addition and subtraction). If any of this information is omitted, the drawing promptly loses a high proportion of its value. Blacking-in the sky outside the disk makes the drawing look more impressive, but is not actually necessary.

It cannot be too strongly emphasized that extreme care is essential when making an observation of Mars. One good drawing is worth more than a hundred fairly good ones. Moreover, no details should be recorded unless they have been seen with absolute certainty.

APPENDIX II

NUMERICAL DATA

Mars

Distance from the Sun:	max. 154,500,000 miles = 1·666 astronomical units*
	mean 141,500,000 miles = 1·524 astronomical units
	min. 128,500,000 miles = 1·383 astronomical units
Distance from the Earth:	max. 248,600,000 miles
	min. 34,000,000 miles
Axial rotation:	24 hours 37 minutes 22·7 seconds
Sidereal period ("year"):	686·98 Earth days = 668·60 Martian days
Orbital velocity, miles per second:	max. 16·5, mean 15·0, min. 13·6
Orbital inclination:	1° 50′ 59″·8 = 1°·9
Orbital eccentricity:	0·093
Diameter:	4,219 miles
Mass (Earth = 1):	0·108
Volume (Earth = 1):	0·151
Escape velocity:	3·13 miles per second
Density (Earth = 1):	0·71
(Water = 1):	3·91
Surface gravity (Earth = 1):	0·38
Surface area (Earth = 1):	0·28
Mean sidereal motion in 24 hours:	1886·52 seconds of arc

* 1 astronomical unit = the Earth–Sun distance = 93,000,000 miles.

The Satellites

	Phobos	*Deimos*
Discoverer:	Hall, 1877 Aug. 16	Hall, 1877 Aug. 11
Mean distance from centre of Mars:	5,800 miles	14,600 miles
Periodic time:	7h 39m = 0·3189d	30h 18m = 1·2624d
Orbital eccentricity:	0·0210	0·0028
Orbital inclination:	1°·13	1°·77
Mean angular distance from Mars, at mean opposition distance:	24″·7	1′ 01″·8
Diameter:	10 to 12 miles	5 to 6 miles
Apparent star magnitude, at mean opposition distance:	10 to 12	11 to 12

The values for the orbits are as given by H. E. Burton (95).

APPENDIX III

OBSERVATIONAL SOCIETIES AND PROGRAMMES

THE AMATEUR observer will find it greatly to his advantage to join an astronomical society. In Britain, the leading mainly amateur society is the British Astronomical Association (303 Bath Road, Hounslow West, Middlesex), founded in 1890. The section devoted exclusively to Mars is directed by E. H. Collinson; 15 full-length Memoirs have been issued, as well as hundreds of notes, reports and observations scattered through the monthly *Journal*.

There are many local astronomical societies in both England and Scotland; these are listed in the annual *Yearbook of Astronomy*, edited by J. G. Porter and published in London each November.

The nearest U.S. equivalent of the B.A.A. is the Association of Lunar and Planetary Observers, directed by W. H. Haas (Box 26, University Park, New Mexico, U.S.A.). Its periodical, the *Strolling Astronomer*, is most informative. The A.L.P.O. Mars Section is directed by Ernst E. Both, of the Buffalo Museum of Science.

APPENDIX IV

OLD AND NEW NOMENCLATURE OF MARTIAN FEATURES

N. E. GREEN's map of Mars, reproduced on page 33, uses the old system of nomenclature; it is interesting to make comparisons with the modern names, most of which were introduced by Schiaparelli. Some of the identifications are somewhat dubious, and the features referred to by Green as Pratt Bay and Schmidt Bay have been omitted from the list.

Green's name	*Modern name*
Airy Sea	Mare Boreum
Beer Continent	Æria, Arabia, Moab
Burckhardt Land	Hesperia
Burton Bay	Margaritifer Sinus
Cassini Land	Ausonia
Christie Bay	Auroræ Sinus
Dawes' Forked Bay	Sinus Meridiani
Delambre Sea	Umbra
De la Rue Ocean	Mare Erythræum
Flammarion Sea	Mare Tyrrhenum
Fontana Land	Dioscuria, Cydonia
Herschel I. Continent	Elysium, Æthiopis, Æolis
Herschel II. Strait	Sinus Sabæus
Huggins Bay	Sinus Gomen
Jacob Land	Argyre
Kaïser Sea	Syrtis Major
Lockyer Land	Hellas
Mädler Continent	Chryse, Xanthe
Main Sea	Mœris Lacus

Maraldi Sea	Mare Cimmerium
Oudemans Sea	Utopia
Phillips Island	Deucalionis Regio
Rosse Land	Tempe, Arcadia
Secchi Continent	Memnonia
Terby Sea	Solis Lacus
Webb Land	Eridania

APPENDIX V

DESCRIPTION OF THE SURFACE

THE NOMENCLATURE of Mars has recently been overhauled by the International Astronomical Union; for instance, the ochre area formerly termed Eden has been marked on the I.A.U. map as "Moab". The description which follows is by no means exhaustive, and is meant to be nothing but a general guide; however, large telescopes are needed to show the finer features.

ACIDALIUM, MARE. The main dark region of the northern hemisphere, and very prominent when the north pole is tilted towards the Earth, as in 1963. A modest telescope will show it when it is well placed. Its southernmost extension is perhaps best regarded as a separate feature, and is known as the NILIACUS LACUS.

ÆOLIS. Part of the ochre area north of Mare Cimmerium. Other similar areas, extending down to the far north, are ÆTHIOPIS, ELYSIUM, ÆTHERIA, PHLEGRA and ZEPHYRIA. The centre of the whole area is occupied by the interesting Trivium Charontis.

ÆRIA. An extensive ochre tract adjoining the Syrtis Major, and joining the very similar ARABIA, which in turn joins MOAB. The whole area is said to be crossed by several canals: the PHISON, the EUPHRATES, and the HIDDEKEL and GEHON, which issue from the "forks" of the Sinus Meridiani. These canals were among those said by Schiaparelli and Lowell to show the phenomenon of gemination.

AMAZONIS. A very large ochre area, crossed by the equator, well north of the Mare Sirenum. It contains the NIX OLYMPICA,

which has been described in the text. Amazonis joins on to Memnonia, Arcadia and Diacria.

AONIUS SINUS. A dark patch in the main southern band, between the Mare Sirenum and the Mare Australe.

ARCADIA. This is one of the larger northern "deserts", and lies between Amazonis (which it somewhat resembles) and the Mare Boreum. I have never seen much detail in it.

ARGYRE. This separates the Mare Australe from the Mare Erythræum area. Like Hellas, it often appears as white, though it is not generally so conspicuous or so well-defined as Hellas. It may well be an elevated area.

AURORÆ SINUS. A pronounced and often well-defined dark patch adjoining the Mare Erythræum. It is separated from the Margaritifer Sinus by the small but distinct PYRRHÆ REGIO. Close to it lies the much smaller JUVENTÆ FONS, which I admit that I have never been able to see with any certainty.

AUSONIA. A light area dividing the Mare Tyrrhenum from the Mare Hadriacum, and extending up towards Mare Chronium. It is often very distinct, as was the case in 1961, when it was usually a very easy object.

BALTIA. Part of the northern dark band. It is of the same type as areas such as ORTYGIA, SCANDIA, CECROPIA and PANCHAÏA, none of which have well-marked boundaries.

BOREUM, MARE. One of the darker northern areas: it adjoins the Mare Acidalium, and may in fact be a part of it. I always find it hard to decide where the Mare Acidalium ends and the Mare Boreum begins.

CASIUS. The famous "wedge", extending from the BOREOSYRTIS. It is most certainly not a canal in any sense of the word. It joins the equally uncanal-like Nepenthes-Thoth, and is situated at the edge of the small but quite distinct light area known as NEITH REGIO.

CEBRENIA. A light area north of Elysium, and bounded by Panchaïa. It is also connected with Ætheria.

CERBERUS. A famous canal extending from the Trivium Charontis. It is nothing like a canal, but at least it

definitely exists, and I find it quite easy in an 8½-inch reflector when Mars is well-placed.

CHRONIUM, MARE. A dark area in the far south. It is separated from the Mare Cimmerium by the light area of ERIDANIA.

CHRYSE. This and the similar XANTHE lie close to the equator in the general area of Auroræ Sinus. They are said to be separated by a canal, the JAMUNA, which has always eluded me even with the Meudon refractor. However, its existence is well-authenticated, so presumably I simply overlooked it.

CIMMERIUM, MARE. One of the most prominent of the southern dark areas, and with a characteristic shape which makes it unmistakable. It is always a very easy object when suitably placed, and is visible in a 3-inch refractor.

DELTATON SINUS. An extension of the Syrtis Major, joining on to the Sinus Sabæus. It is lighter than either of these areas.

DEUCALIONIS REGIO. An elongated light area, often very prominent, separating the Sinus Sabæus from the Pandoræ Fretum.

DEUTERONILUS. A broad streaky feature running from the Ismenius Lacus to the Niliacus Lacus. It is not a difficult object under good conditions. Very similar is the PROTONILUS, which runs from the opposite side of the Ismenius Lacus and joins the even broader NILOSYRTIS. Schiaparelli drew all three as one continuous canal, and joined them up to the tip of the Syrtis Major.

ELECTRIS. A reasonably well-defined and often lightish area adjoining Eridania, in the region of the Mare Chronium and Mare Cimmerium.

ERYTHRÆUM, MARE. An extremely prominent and complex dark region. It is one of the most conspicuous features of the entire disk. It is joined on to the Auroræ Sinus and the Margaritifer Sinus.

HADRIACUM, MARE. A curved dark feature, bordering Hellas and usually easy to find. It extends from IAPIGIA, which may be regarded as the southern part of the Syrtis Major.

HELLAS. This extremely interesting feature, often strongly white, has been fully described in the text. It can usually be made out even when Mars is a long way from opposition, provided of course that the southern hemisphere is displayed. Schiaparelli drew two canals, the Alpheus and the Peneus, crossing it; I can only say that I have never seen a trace of either. To the east, Hellas is bordered by the Mare Hadriacum.

HELLESPONTUS. This variable feature, whose development is closely linked with the seasonal cycle, has also been dealt with in the text.

HESPERIA. A light area dividing the Mare Cimmerium from the Mare Tyrrhenum. It is very prominent under normal conditions, as in 1956, 1958 and again in 1960.

ISIDIS REGIO. A well-defined ochre area on the edge of the Syrtis Major. It joins the Neith Regio, and is bordered to the east by the Nepenthes-Thoth. It can often appear bright, partly because of contrast with the very dark Syrtis Major.

ISMENIUS LACUS. A dark patch east of the Mare Acidalium, in the northern hemisphere. It has already been mentioned in connection with the Deuteronilus. Generally it is quite prominent.

LIBYA. The ochre area separating the Mare Tyrrhenum on one side from the Syrtis Major and Mœris Lacus on the other. It is of the same type as Hesperia, and is usually easy to identify.

LUNÆ PALUS. A prominent dark patch between Xanthe and Tractus Albus. It is probably of the same type as the Tithonius Lacus, though it is not so conspicuous. From it, towards the Mare Acidalium, extends the NILOKERAS, another of the broad, streaky features which are so uncanaliform in aspect. Schiaparelli, however, drew the Nilokeras as a double canal, and also showed several more canals radiating from the Lunæ Palus (marked in his map as the Lunæ Lacus, and still commonly known as such).

MARGARITIFER SINUS. Another of the V-shaped features of the southern dark band. It is prominent, and the unwary observer may easily mistake it for the Syrtis Major. It extends from the Mare Erythræum, and is separated from the Sinus Meridiani by the ochre THYMIAMATA. Closely south of it is the small but sometimes distinct patch of the OXIA PALUS. A canal, the OXUS, is said to stretch from here to the Deuteronilus; I have yet to see it.

MEMNONIA. An ochre area between Amazonis and the Mare Sirenum.

MERIDIANI SINUS. The Martian "Greenwich". It is not too easy an object, but it is dark at times.

NECTAR. A dark patch between the Solis Lacus and the Mare Erythræum. It was one of Schiaparelli's canals.

NEPENTHES-THOTH. A dark streaky feature running from the Mœris Lacus, which adjoins the Syrtis Major, to the Wedge of Casius. It is not identifiable on Schiaparelli's map; instead Schiaparelli shows a delicate canal which he called the Athur. Yet the Nepenthes-Thoth is very conspicuous at times.

NOACHIS. Another area which has points of resemblance to Hellas, Ausonia, Eridania, Electris and Argyre. It, too, can show up as whitish on occasions.

PANDORÆ FRETUM. A dusky, streaky region south of the Sinus Sabæus, and separated from it by Deucalionis Regio. The Pandoræ Fretum shows unusual variations in conspicuousness.

PHÆTHONTIS. A lightish region extending from the Mare Sirenum.

PHŒNICIS LACUS. A small dark patch west of the Tithonius Lacus. Schiaparelli showed it as a centre of radiating canals, the Araxes, Phasis, and others, of which only the Araxes is shown on the I.A.U. map.

PROPONTIS. An elongated dark region in the north, bordering on Diacria. It ends in the east at a patch which has been known as the Castorius Lacus, but which is not named on the I.A.U. chart.

SABÆUS SINUS. One of the main features of the disk, and always identifiable except when the entire area is hidden by atmospheric obscuration. It connects the Syrtis Major with the Sinus Meridiani.

SIRENUM, MARE. Another very prominent feature of the southern hemisphere. It, too, is slightly V-shaped. From its "beak", to the east, extends the streaky ARAXES, shown by Schiaparelli as a canal, and which runs to the Phœnicis Lacus.

SOLIS LACUS. The celebrated variable area, described in the text. On the older maps it was placed in the centre of an orange tract, THAUMASIA. Thaumasia is still shown, but has been cut up, since other parts of the tract are now termed CLARITAS, SYRIA and SINAÏ.

SYRTIS MAJOR. This is much the most prominent dark region on all Mars. It has been referred to frequently in the text, and there is no need to say more about it here.

TEMPE. An ochre area in the north, bordered by TANAÏS, Nilokeras and Tractus Albus, and connected with Arcadia. I have seen it lightish occasionally.

THYLE I and THYLE II. White areas in the far south, between the pole and the Mare Chronium.

TITHONIUS LACUS. This, too, has been fully described. In 1960–1961 I found that it was often one of the most striking features on view. On the "canal" maps, it is the centre of a radiating system; canals named include the Agathodæmon, Chrysorrhaas, Fortune, and (running to the Lacus Phœnicis and on to the beak of the Mare Sirenum) the ARAXES. Only the Araxes is named on the I.A.U. map, but I have often seen a streaky object which I believe to be the old Agathodæmon, together with indications of the Chrysorrhaas.

TRIVIUM CHARONTIS. Another famous object, this time in the ochre tract made up of Elysium, Zephyria and the rest. According to Lowell and Schiaparelli, it was one of the main canal centres of Mars; among the canals shown were the STYX, LÆSTRYGON, CERBERUS, Orcus, Hades,

Erebus and others. The first three are named on modern maps, and definitely exist. They are not narrow canals, but they are streaky, and seem really to issue from the Trivium Charontis.

TYRRHENUM, MARE. A dark, very prominent region between the Syrtis Major and the Mare Cimmerium. It is always easy to identify.

CO-ORDINATES OF MARTIAN FEATURES

[See map on pages 24 and 25]

Acidalium, Mare	30°	+45°	Chryse	30	+10
Æolis	215	−5	Chrysokeras	110	−50
Æria	310	+10	Cimmerium,		
Ætheria	230	+40	Mare	220	−20
Æthiopis	230	+10	Claritas	110	−35
Amazonis	140	0	Copaïs Palus	280	+55
Amenthes	250	+5	Coprates	65	−15
Aonius Sinus	105	−45	Cyclopia	230	−5
Arabia	330	+20	Cydonia	0	+40
Araxes	115	−25			
Arcadia	100	+45	Deltaton Sinus	305	−4
Argyre	25	−45	Deucalionis		
Arnon	335	+48	Regio	340	−15
Auroræ Sinus	50	−15	Deuteronilus	0	+35
Ausonia	250	−40	Diacria	180	+50
Australe, Mare	40	−60	Dioscuria	320	+50
Baltia	50	+60	Edom	345	0
Boreum, Mare	90	+50	Electris	190	−45
Boreosyrtis	290	+55	Elysium	210	+25
			Eridania	220	−45
Candor	75	+3	Erythræum, Mare	40	−25
Casius	260	+40	Eunostos	220	+22
Cebrenia	210	+50	Euphrates	335	+20
Cecropia	320	+60			
Ceraunius	95	+20	Gehon	0	+15
Cerberus	205	+15			
Chalce	0	−50	Hadriacum,		
Chersonesus	260	−50	Mare	270	−40
Chronium, Mare	210	−58	Hellas	290	−40

Hellespontica Depressio	340	−60
Hellespontus	325	−50
Hesperia	240	−20
Hiddekel	345	+15
Hyperboreus Lacus	60	+75
Iapigia	295	−20
Icaria	130	−40
Isidis Regio	275	+20
Ismenius Lacus	330	+40
Jamuna	40	+10
Juventæ Fons	63	−5
Læstrygon	200	0
Lemuria	200	+70
Libya	270	0
Lunæ Palus	65	+15
Margaritifer Sinus	25	−10
Memnonia	150	−20
Meroe	285	+35
Meridiani Sinus	0	−5
Moab	350	+20
Mœris Lacus	270	+8
Nectar	72	−28
Neith Regio	270	+35
Nepenthes	260	+20
Nereidum Fretum	55	−45
Niliacus Lacus	30	+30
Nilokeras	55	+30
Nilosyrtis	290	+42
Nix Olympica	130	+20
Noachis	330	−45
Ogygis Regio	65	−45
Olympia	200	+80
Ophir	65	−10
Ortygia	0	+60
Oxia Palus	18	+8
Oxus	10	+20
Panchaïa	200	+60
Pandoræ Fretum	340	−25
Phæthontis	155	−50
Phison	320	+20
Phlegra	190	+30
Phœnicis Lacus	110	−12
Phrixi Regio	70	−40
Promethei Sinus	280	−65
Propontis	185	+45
Protei Regio	50	−23
Protonilus	315	+42
Pyrrhæ Regio	38	−15
Sabæus Sinus	340	−8
Scandia	150	+60
Serpentis, Mare	320	−30
Sinaï	70	−20
Sirenum, Mare	155	−30
Sithonius Lacus	245	+45
Solis Lacus	90	−28
Styx	200	+30
Syria	100	−20
Syrtis Major	290	+10
Tanaïs	70	+50
Tempe	70	+40
Thaumasia	85	−35
Thoth	255	+30

Thyle I	180	−70
Thyle II	230	−70
Thymiamata	10	+10
Tithonius Lacus	85	−5
Tractus Albus	80	+30
Trinacria	268	−25
Trivium Charontis	198	+20
Tyrrhenum, Mare	255	−20
Uchronia	260	+70
Umbra	290	+50
Utopia	250	+50
Vulcani Pelagus	15	−35
Xanthe	50	+10
Yaonis Regio	320	−40
Zephyria	195	0

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Abbreviations:

JBAA = Journal of the British Astronomical Association.
PASP = Publications of the Astronomical Society of the Pacific.
CR = Comptes Rendus de l'Académie des Sciences de Paris.
AJ = Astrophysical Journal.

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There have been so many books about Mars that I do not propose to make any attempt to list them. Among those which are of particularly obvious value to anyone really interested in Martian matters are:

Mars, by E. C. Slipher (Sky Publishing Corporation, 1962), an account of the Lowell Observatory studies of Mars, with a magnificent series of photographs of the planet.

Physics of the Planet Mars, by G. de Vaucouleurs (London 1954), which is a technical study and has been referred to frequently in the present book (Faber & Faber).

The Planet Mars, also by G. de Vaucouleurs (London, 1950), a

much shorter introduction, published in English in several editions (also Faber & Faber).

The Green and Red Planet, by Hubertus Strughold (London, 1954), which deals with the problems of Mars from the biological viewpoint (Sidgwick & Jackson).

La Planète Mars, by E. M. Antoniadi, which was published in Paris in 1930, but is now, naturally, out of date in some respects.

I hope that something may also be gained from *Life on Mars*, by F. L. Jackson and myself (Routledge and Kegan Paul, London 1965), which treats the whole problem from a biological as well as an astronomical viewpoint.

There is a most valuable article, Problems of Mars, by G. de Vaucouleurs, in the *Yearbook of Astronomy for 1963*, edited by J. G. Porter and published by Eyre & Spottiswoode. Many relevant articles are to be found in *Sky and Telescope*, the monthly periodical issued from Cambridge, Massachusetts, and in society publications, such as those of the B.A.A. and the A.L.P.O. Many original and important articles are published in the *Publications* of the Astronomical Society of the Pacific.

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guide to mars

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